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THE ACADIAN TRIASSIC

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PART I

INTRODUCTION

GENERAL RELATIONS

The Acadian Triassic is preserved as a rather narrow, discontinuous border to the Bay of Fundy and Minas Basin. The Bay of Fundy has a northeast-southwest trend, with the island of Grand Manan at the entrance. The Triassic extends from the southwest end of Grand Manan to Truro, a distance of 195 miles. The width of the Bay of Fundy, from Digby to St. John, is 45 miles. On both the New Brunswick and the Nova Scotia shore, the Triassic appears: in New Brunswick on Grand Manan Island, at Split Rock (Gardner's Creek), Quaco, Martin Head, and Waterside; in Nova Scotia on the island of Isle Haute, and in a quite continuous strip from Advocate around Minas Basin and down the Bay of Fundy to Brier Island at the entrance.

The field work in connection with this paper occupied a portion of the summers of 1913 and 1914. In the field work, the writer is indebted for suggestions to Professor J. W. Goldthwait, Dr.

A. O. Hayes, and Mr. W. A. Bell of the Geological Survey of Canada, and to Professor D. S. McIntosh of Halifax, Nova Scotia. Professor Alfred C. Lane of Tufts College has kindly permitted the use of thin sections and drill cores of the Cape D'Or basalt. To Professor R. A. Daly, under whose direction this paper was prepared as a portion of a thesis for the degree of Doctor of Philosophy in Harvard University, special thanks are due for helpful criticism.

GENERAL GEOGRAPHY AND GEOLOGY OF THE REGION

Topography.—The most important topographic feature of the Bay of Fundy region is North Mountain, extending from Cape Blomidon to Brier Island, 125 miles. South of North Mountain is the Annapolis Valley and the land of Evangeline, a broad fertile plain extending from Minas Basin to the Annapolis Basin. South of the Annapolis Valley is South Mountain, whose crest stands on a level with North Mountain, at an elevation of about 400 feet.

On the northern side of the Bay is the island of Grand Manan, presenting an abrupt escarpment on the west, rising 200 to 400 feet out of the sea. The tops of these basaltic cliffs is again at the level of North Mountain. On the east side of Grand Manan is a rolling lowland fronted by many islands. The New Brunswick shore is bounded by rocky cliffs rising to a height of 50 to 200 feet, but between the Triassic exposures at Quaco and Waterside, the cliffs rise to the summit level of 400 feet.

Minas Basin is surrounded by lowlands, presenting a rather flat surface at elevations of 100 to 150 feet, except for the tidal marshes. On the north, the Cobequid Mountains rise to heights of 500 to 800 feet, with "peaks" at 1,000 feet.

Geology.—The controlling factor of the topography and geology of the region is the direction of the orographic axes, from northeast to southwest (Fig. 1). The Bay of Fundy is confined between a broad belt of pre-Cambrian rocks in Nova Scotia, fronted by the Triassic; and a less broad belt of pre-Cambrian rocks in New Brunswick, fronted by Carboniferous and Triassic strata (Fig. 2). The peninsula of Nova Scotia is composed largely of pre-Cambrian strata intruded by Devonian granite.

Minas Basin is bounded by Triassic rocks, below and around which are Carboniferous and Permian strata. To the north, separated by a normal fault, are the Cobequid Mountains, which are composed of Silurian schists and quartzites with various

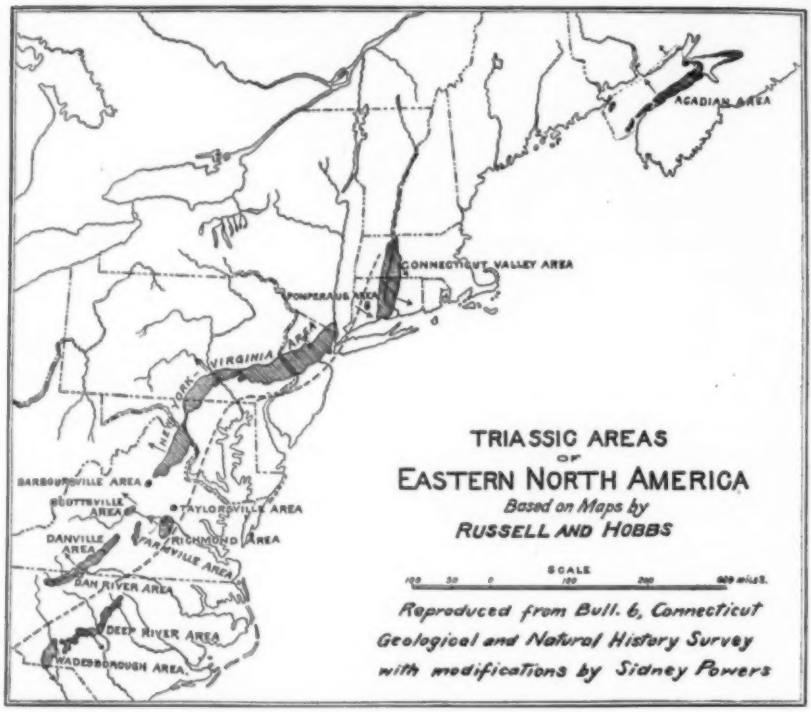

FIG. 1.—The Newark group in North America

associated igneous rocks. North and west of the Cobequids are Carboniferous and Permian strata, stretching northward over the Magdalen Islands and over Prince Edward Island.

THE NEWARK GROUP IN THE ACADIAN AREA

The first reference to the Triassic in the Maritime Provinces is by Alger, in 1827.[1] Six years later, a description of the Triassic

[1] F. Alger, "Notes on the Mineralogy of Nova Scotia," *Am. Jour. Sci.*, XII (1827), 227–32.

rocks was published by Jackson and Alger.[1] At about that time Gesner began his work in connection with the Geological Survey of New Brunswick and mentions the Triassic in each of his reports.[2]

From 1835 to the present, a number of writers have discussed the Acadian Triassic in part or in whole, and, as Russell has given a bibliography of these papers in his correlation paper on "The Newark System,"[3] only the more important and the recent papers need be noted here.

Dana gave the name "Acadian Area" to this mass of Triassic rocks in his *Manual of Geology* (2d ed., 1875). Three years later, Dawson issued the second edition of his *Acadian Geology*, in which volume is the only account of the Triassic in Nova Scotia and New Brunswick. From 1863 to 1880, G. F. Matthew and L. W. Bailey were employed by the Geological Survey of Canada in mapping southern New Brunswick. In their reports are descriptions of the outliers of Triassic strata in New Brunswick.

The more recent work on the Acadian Triassic is that published by L. W. Bailey on the Digby Neck region[4] and by H. Fletcher

FIG. 2.—Geologic cross-section, AA, of the entrance to the Bay of Fundy, through Quoddy Head, Maine, on the northwest, the island of Grand Manan near by, and Long Island on the southeast. *P*, pre-Cambrian; *B*, Meguma series (pre-Cambrian); *S*, Silurian; *Di*, Diabase (Devonian ?); *T*, Triassic. The Triassic shales under the basalt on Grand Manan appear only on the north. The Triassic sediments south of Long Island are submerged. Note the longitudinal valley on Long Island between the flows.

[1] C. T. Jackson and F. Alger, "Remarks on the Mineralogy and Geology of Nova Scotia," *Am. Acad., Mem.*, N.S., I, 217–330.

[2] The reports are given in the bibliography of all literature on the Newark System, in I. C. Russell's correlation paper on "The Newark System," *U.S. Geol. Surv., Bull. 85*, 1892.

[3] *Ibid.*

[4] L. W. Bailey, "Report on the Geology of Southwestern Nova Scotia," *Geol. Surv. Canada, Ann. Rept.*, IX (1898), Part M.

who mapped the Minas Basin region[1] for the Geological Survey of Canada.

The former extent of the Acadian area is indeterminate, but it is probable that it extended several miles in all directions beyond the present boundaries. The original form appears to have been a basin with its northern limit near the Cobequid Mountains and its southern limit not far south of Grand Manan and Brier Island. There may have been a ridge of older rock extending out into the basin where the eastern side of Grand Manan now is, provided that the interpretation of the geology of that island, as given below, is correct.

The Newark group in the Acadian area has been divided into the following formation:

	Thickness in Feet
Top, an erosion surface	
Scots Bay formation (calcareous white sandstone)	25–(2,000?)
North Mountain basalt (a succession of lava flows)	800– 1,000
Annapolis formation (red beds, largely calcareous)	
Blomidan shale	500– 1,000
Wolfville sandstone	2,000– 2,500
	3,325– 6,500
Base, an unconformity with Paleozoic or older rocks	

Interbedded in the Annapolis formation, near its top, are certain basalt flows: agglomerate and tuff beds near the Five Islands, grouped under the name Five Islands volcanics. At Quaco, New Brunswick, there is a conglomerate horizon in the center of the red sandstones correlated with the Annapolis formation, and this conglomerate is called the Quaco conglomerate.

DESCRIPTIVE GEOLOGY

The descriptive geology of the Acadian Triassic will be taken up by localities, giving a brief description of the lithological and structural details. A number of detailed maps and sections are introduced, which may be connected with the region as a whole, by reference to the general map (Fig. 3), and the columnar sections

[1] H. Fletcher, various papers which have been printed in the annual and summary reports of the Geological Survey of Canada from 1887 to 1907. See especially the *Annual Report*, V (1892), Part P.

(Fig. 4). The principal structural features and the details concerning the igneous rocks are summarized in a separate section.

STRATIGRAPHY

Grand Manan.—The island of Grand Manan is situated 4 miles southwest of Quoddy Head, the most easterly point in the United States. It is 15 miles long and 6 miles wide in the widest part. To the east and south are numerous islands and reefs.

Grand Manan was first visited by a geologist—Abraham Gesner—in 1838, then by Bailey,[1] Verrill,[2] and Ells.[3] Bailey visited most of the adjoining islands and gives the best description of the geology.

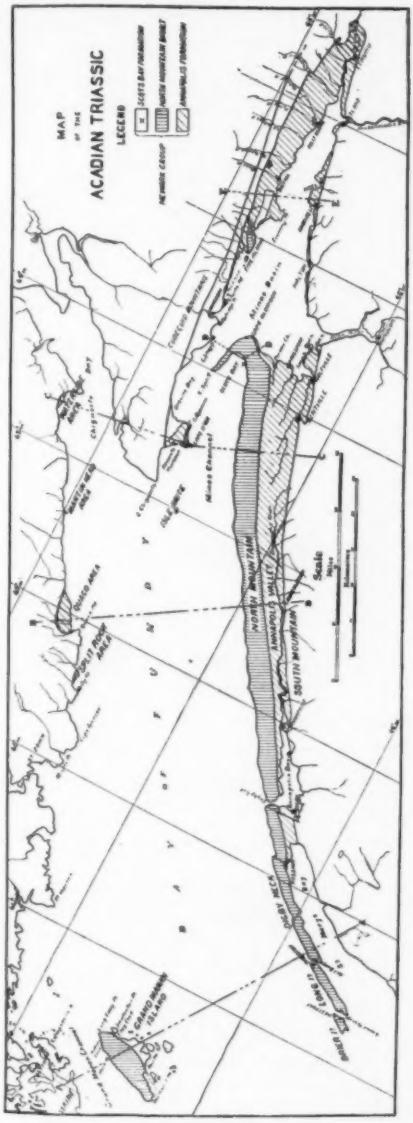

FIG. 3.—Map of the Acadian Triassic

[1] L. W. Bailey, "The Physiography and Geology of the Island of Grand Manan," *Can. Nat.*, VI (1872), 43 ff.; also see Bailey, Matthew, and Ells, "Preliminary Report on the Geology of Southern New Brunswick," *Geol. Surv. Canada, Rept. Progress* (1870), pp. 216–21.

[2] A. E. Verrill, Appendix E to Dawson's *Acadian Geology*, 3d ed. (1878), pp. 679–80.

[3] R. W. Ells, *Geol. Surv. Canada, Summary Rept.*, VIII (1894), 271*A*.

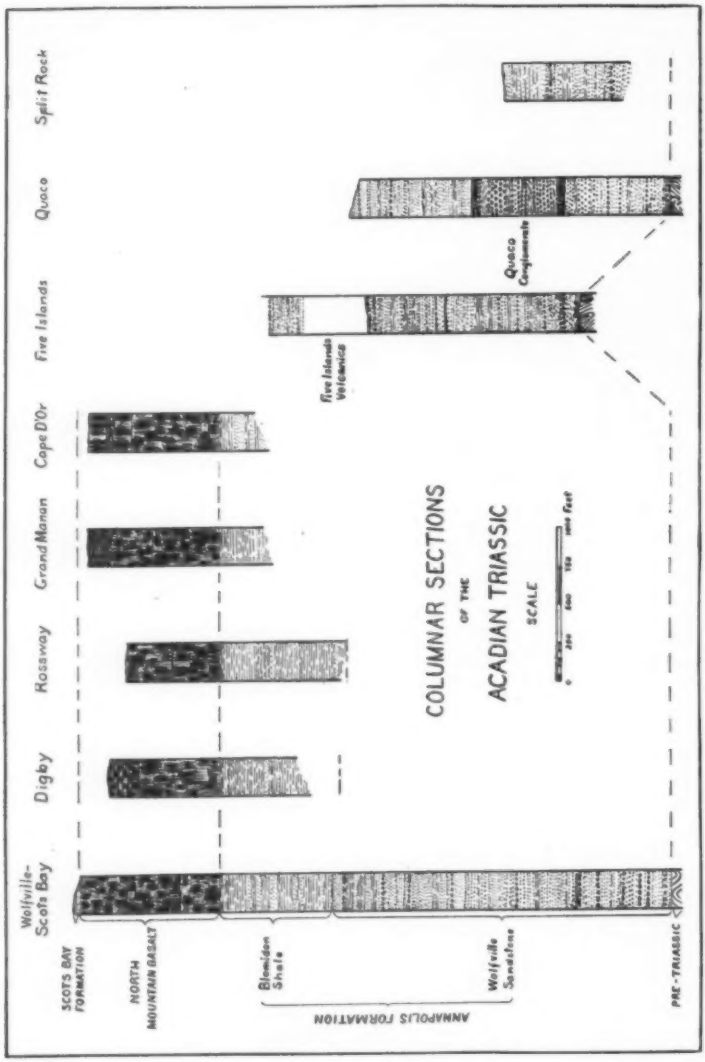

FIG. 4.—Columnar sections of the Acadian Triassic

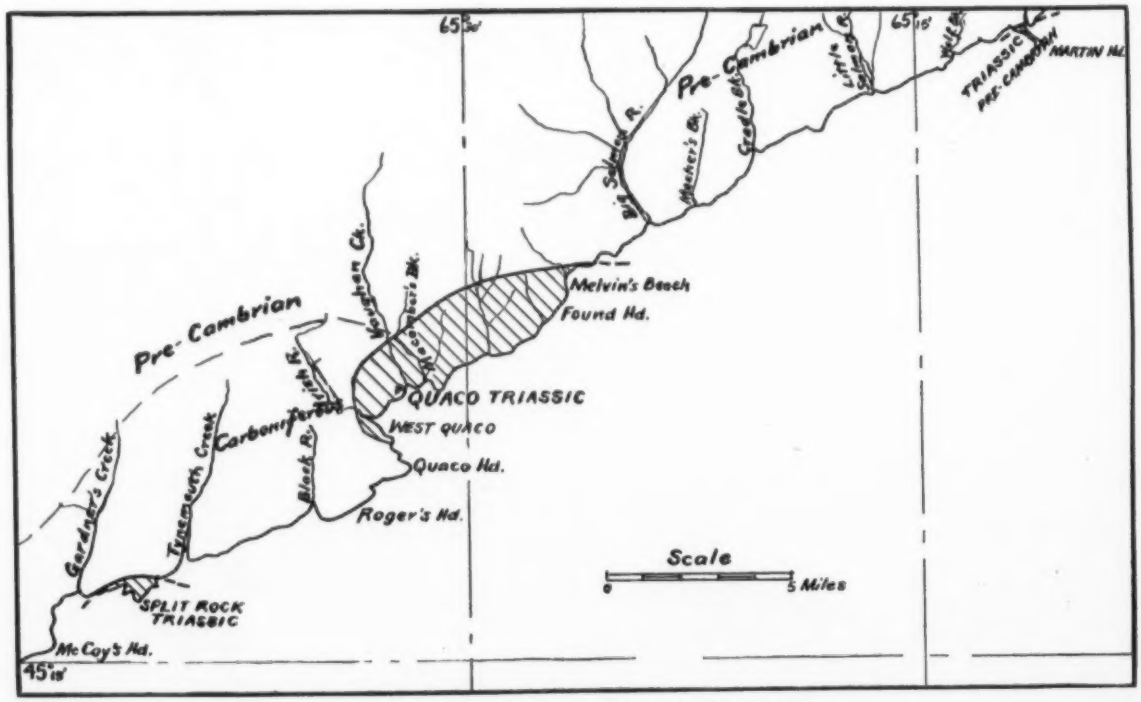

FIG. 5.—Map of the Split Rock, Quaco, and Martin Head, Triassic areas

The physiography and geology of Grand Manan divide the island into two provinces: a western upland underlain by Triassic basalt flows, and an eastern lowland underlain by pre-Silurian[1] metamorphic rocks. The upland represents the level of the Summit[2] peneplain, at elevations of 200–400 feet. The western coast of the island is fronted by cliffs rising abruptly in an almost straight line to a height of 100–300 feet.

The Triassic rocks of the island consist of basalt flows underlain by purple shale. The shale is exposed to a thickness of only 50 feet, and this exposure is at Dark Harbour, on the western side of the island. The basalts rest directly on older, metamorphic rocks on the eastern side of the island; at Red Head, on the south, and at the northwestern end of Flag Cove, on the north. At the former locality the contact dips 35 degrees, suggesting a fault, but the recent weathering of the rocks near the contact obscures the exposure.

The basalt flows are thick at the base and thin at the top. The exact thicknesses are given below with the résumé of the igneous rocks. The dip of the flows is variable. At Dark Harbour it is practically horizontal, but north of this place, the dip is down toward the north at angles of 5 to 15 degrees. It is difficult to determine the horizontal extent of any one flow. Diabase dikes are reported by Bailey at several places, one of which is Swallow-Tail Light.

The faults on Grand Manan are obscured by the massive character of the basalt. The major fault bounds the west side of the island, and the cliffs, which run in an almost straight line for 15 miles, mark the fault-line scarp. East-west faults are less prominent. One may occur at Dark Harbour, as many of the streams flowing across the Newark basalts follow fault-lines. Minor faults are seen in the shore exposures.

Split Rock.—Eighteen miles east of St. John, between Gardner's Creek and Tynemouth Creek, there is a strip of Triassic sediments

[1] The age of these rocks is probably pre-Cambrian, as they are older than the Silurian rocks of the Eastport Quadrangle. See E. S. Bastin, *U.S. Geol. Survey, Geol. Atlas*, Eastport Folio (No. 192) (1914), p. 14.

[2] The term "Summit" peneplain is used instead of "Cretaceous" peneplain in order to avoid any reference to the age of this topographic feature.

about two miles long, and three-quarters of a mile wide at Split Rock itself (Figs. 5 and 6). This point should not be confused with one southwest of St. John by the same name.

This area is bounded on the north by a fault which has brought the Triassic into contact with the Carboniferous. The dip of the

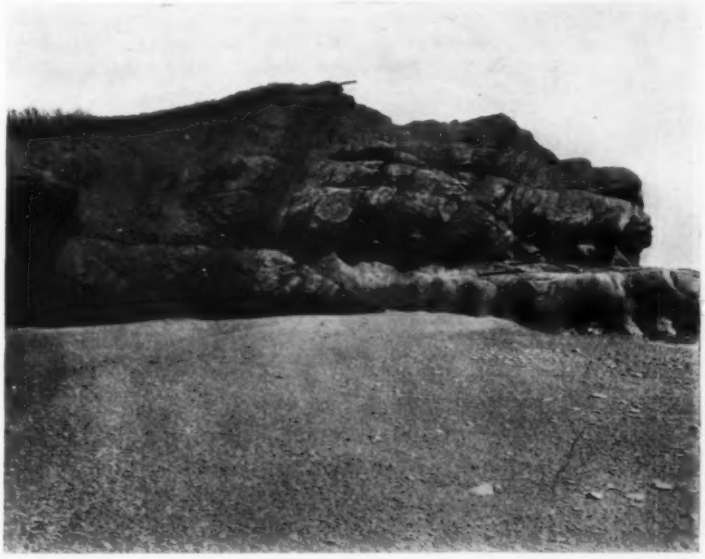

FIG. 6.—The Triassic shales near Gardner's Creek (Split Rock), dipping northward. The marine shelf has been cut at high tide level.

Triassic red sandstones, shales, and occasional conglomerates is in general northward at angles of about 45 degrees, but the beds flatten out at split rock itself. The sediments show occasional cross-bedding. The conglomerates contain only occasional pebbles, and these pebbles are subangular, with occasionally very angular, and rarely rounded surfaces. They do not show striations or sand-blasted surfaces. Fragments of silicified wood have been found near Gardner's Creek, and are noted by Dawson in his *Acadian Geology*.

Quaco.—A large area of Triassic sediments occurs at Quaco, now known as St. Martin. The Triassic extends from West Quaco to Melvin's Beach, and includes the large area mapped as

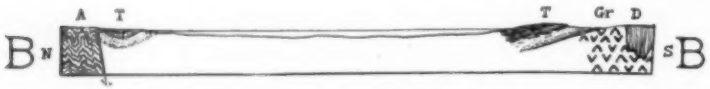

FIG. 7.—Geologic cross-section, BB, from Quaco, on the north, through North Mountain, the Annapolis Valley, and South Mountain, on the south. *A*, pre-Cambrian; *D*, Devonian; *Gr*, Devonian granite; *T*, Triassic.

FIG. 8.—The contact of the lower red sandstone and the Quaco conglomerate above, near Macomber Brook, Quaco. The contact is a conformity. There is a very sharp boundary both in lithology and in color which is obscured by a pile of talus in the center of the picture.

Lower Carboniferous on the map of the Geological Survey of Canada, issued in 1880. The length of the area is $7\frac{1}{2}$ miles and the width 3 miles, as shown in Fig. 5. The shore exposures furnish an excellent structural cross-section of the area.

The structure of the Quaco area is synclinal, with an east-west axis (Figs. 7 and 8). The contact of the Newark rocks with older rocks is shown at West Quaco, where there is an unconformity of red Triassic sandstone on greatly pointed, pre-Triassic traps. The basal sandstone contains occasional pebbles of various kinds of rock but contains no residual soil of the trap. At the unconformity there is minor cross-faulting in a northeasterly direction. At Melvin's Beach, on the northeast, the Triassic sandstones are seen, with steeply dragged dips, in fault-contact with pre-Cambrian metamorphics.

The stratigraphy of the area shows two normal red sandstone members, separated by a conglomerate of pale yellow color. Interbedded in the conglomerate are persistent beds of sandstone, a few inches in thickness, at stratigraphic distances of 10–30 feet, as shown in Fig. 8. The conglomerate is composed of rather loosely consolidated subangular to rounded stream gravels. Many of the pebbles show impressions of one pebble into another, and other recemented fractures.[1] In no other locality of the Acadian Triassic is such a conglomerate found.

The section was estimated as follows:

Upper red sandstone	800–1,000+
Quaco conglomerate	450– 700
Lower red sandstone	300– 300
	1,550–2,000

UNCONFORMITY WITH CARBONIFEROUS

Plant remains occur at several horizons in the Quaco series. Silicified wood was found by the writer within 50 feet of the top of the lower red sandstone, at Vaughan Creek, and by members of the Geological Survey of Canada at other localities. These fossils are correlated with the fragments of lignite from Split Rock and Martin Head. On account of the exposure of the basal unconformity of the Newark at West Quaco, it is probable that the Quaco exposure is to be correlated with the Annapolis formation,

[1] These conglomerates are similar to those of Upper Devonian age on the north side of Scaumenac Bay, Province of Quebec, described by J. M. Clarke, *Bull. Geol. Soc. Am.*, XXVI (1915).

and that it is below the horizon of the North Mountain basalt, as shown in Fig. 4.

Martin Head.—Martin Head is 20 miles northeast of Quaco. The Head itself is composed of a mass of pre-Cambrian strata, 100 feet in height, connected to a point of land by a shingle beach (Fig. 9). On the northern side of the Head is some red clay, apparently of Pleistocene age, which may be underlain by Triassic sediments.

North of the barrier beach are low cliffs of Triassic strata, exposed only on the west side of the peninsula. The bedrock is exposed for half a mile in the form of a syncline, with the longer

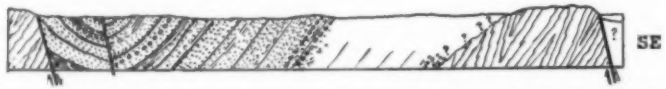

FIG. 9.—Cross-section of the Martin Head Triassic area. Martin Head itself, composed of pre-Cambrian strata, is on the right. Between it and the pre-Cambrian uplands on the northwest are the Triassic sediments. The unconformable contact of the Triassic with the pre-Cambrian on the southeast is hypothetical.

limb on the south. On the north, the Triassic is faulted against the pre-Cambrian, as shown in Fig. 9. In the southern limb 335 feet of sediments are exposed, in the northern limb 85 feet, and between these two limbs there are no exposures. A fault probably exists between the exposures, as the strata do not match on either side of the gap.

The sediments in the Martin Head area are principally yellow sandstones and shales, with occasional pale-red beds, and transition colors. The yellow is a bright-chrome shade, much brighter than that of the Quaco conglomerate, which is merely that of the common stream gravels. Conglomeratic beds occasionally appear. The sediments are characterized by a notable amount of muscovite and of calcite. The former has evidently been derived from the pre-Cambrian mica schists on the north.

Lignite occurs at several horizons in the yellow beds, as carbonized twigs, limbs, and bits of wood, often 2–3 inches in diameter. This lignite has been described by Miss Ruth Holden,[1] and the

[1] Ruth Holden, "Fossil Plants from Eastern Canada," *Annals of Botany*, XXVII (1913), 243–55.

paper is summarized below in treating of the age of the Acadian Triassic. As the plant remains appear to be similar to those found at Quaco, the sediments in the two areas may be correlated with each other.

Waterside.—On the north side of Chignecto Bay is a strip of Triassic at Waterside, 20 miles northeast of Martin Head. The length of the strip is about 4 miles, extending from Dennis' break-water on the west to the eastern end of the marsh at Little Rocher on the east (Fig. 10), but the length of the actual exposures of Triassic sediments is about 1½ miles.

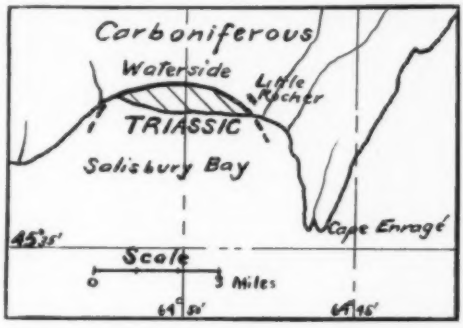

FIG. 10.—Map of the Waterside area of Triassic sediments.

The structure of this area is anticlinal on the west and synclinal on the east, with the axis of the syncline at the Waterside wharf. The dip of the folds is gentle, exposing only 320 feet on the eastern limit of the anticline. On the west,

FIG. 11.—Geologic cross-section, CC, from Waterside, on the north, through Cape d'Or, across Minas Channel, and through North Mountain. *A*, pre-Cambrian; *B*, Meguma series (pre-Cambrian); *SD*, Cobequid group (Silurian, cut by Devonian igneous rocks); *D*, Devonian; *C*, Carboniferous; *T*, Triassic. The major fault of the region is shown in the center of the section, where the Carboniferous and Triassic are dropped down against the Cobequid group.

the Triassic is faulted against a sheared Carboniferous conglomerate, but the contact is concealed by a Pleistocene delta deposit. This same fault probably bounds the Triassic area on the north and east, but it is not again exposed.

The Waterside Newark strata consist of pale-red sandstones with occasional conglomerates. At the top of the series there are

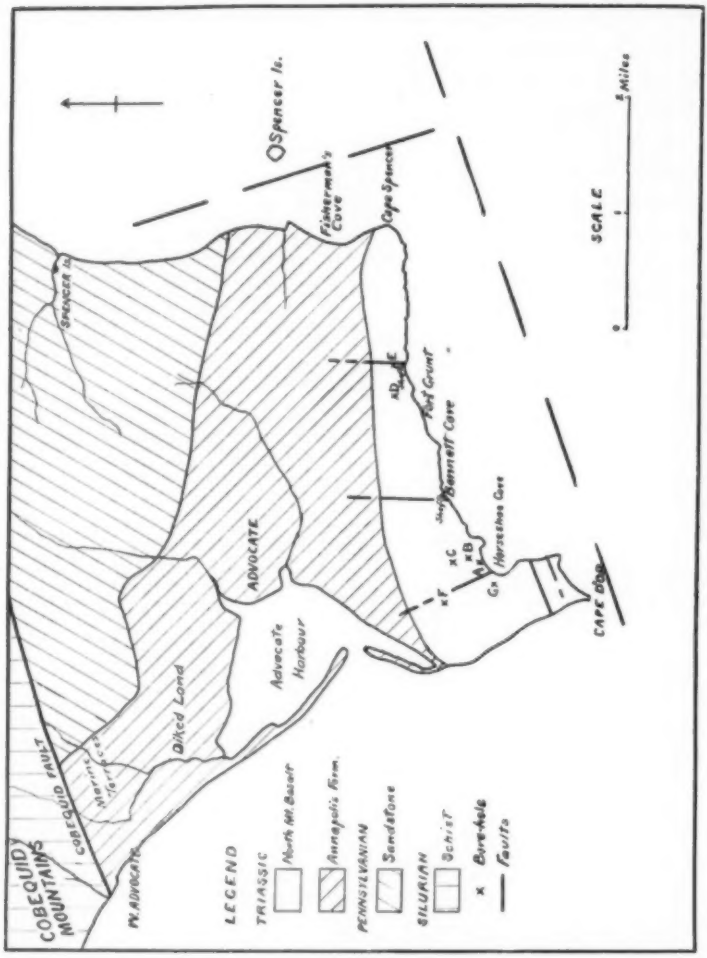

FIG. 12.—Map of the Advocate–Cape d'Or area

several calcitized sandstone beds, which weather out into peculiar forms. Persistent thin green shale or sandstone beds are present.

Contemporaneous erosion channels are seen west of the Waterside wharf.

The Waterside section is to be correlated with the Annapolis formation, but, as no plant remains have been found in it, a more definite correlation is impossible.

Advocate Harbour.—At the southeastern end of Minas Basin is Cape d'Or and north of it is Advocate Harbour. The shore from Cape d'Or to Cape Spencer (Figs. 11, 12) is fronted by basalt

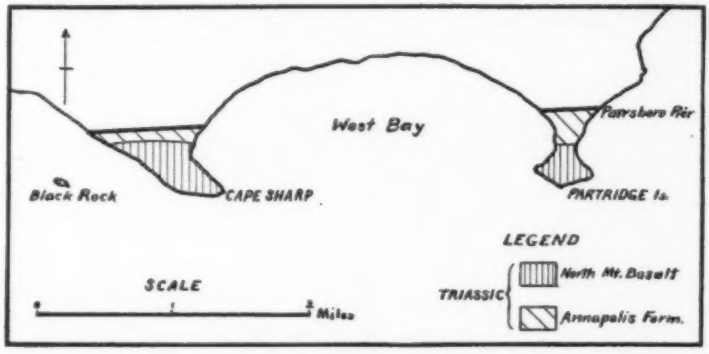

FIG. 13.—Map of the Cape Sharp-Partridge Island region

cliffs 100 feet or more in height. The lowlands on the north are underlain by Triassic sandstone, and, farther north, by Carboniferous sediments. North of the latter are the Cobequid Mountains, fronted by a fault-line scarp rising abruptly from the lowlands.

The upland from Cape d'Or to Cape Spencer, and the islands, Isle Haute and Spencer Island, are composed of basalt flows dipping southward at a low angle. Five flows are exposed at Cape d'Or in drill-cores. The base of the flows rests on Newark shale and sandstone of a white or red color. Both the basal amygdaloid and the underlying sediments are penetrated by gypsum veins.

North of Cape Spencer, very coarse conglomerates, which are probably of Newark age, are exposed. The bowlders in this conglomerate are a foot or two in diameter.

On the shore near West Advocate is the only other exposure of Newark sediments in this area. Red sandstone, with some red

shale, and thin greenish or white bands of sandstone, are dipping eastward. Adjoining these sandstones, on the north, is Silurian carbonaceous schist of the Cobequid group, separated by a fault which may be traced down the beach in a S. 71° W. direction. This is the main Cobequid fault, shown in Fig. 10. Other minor faults are shown in the same map.

FIG. 14.—Partridge Island from the west, showing basalt flows overlying red sandstones. The sandstones appear along the gentle slope at the left-hand side of the cliff.

Cape Sharp.—To the east of Cape Spencer, Cape Sharp is the first promontory. It consists of basalt, as does Black Rock on the west (Fig. 13). On the north of Cape Sharp is a lowland underlain by red Triassic sandstone and shale with occasional green bands, and north of this is a rolling country underlain by Carboniferous sediments.

The basalt on Cape Sharp consists of one or more flows—probably two flows—which dip to the south at an angle of about

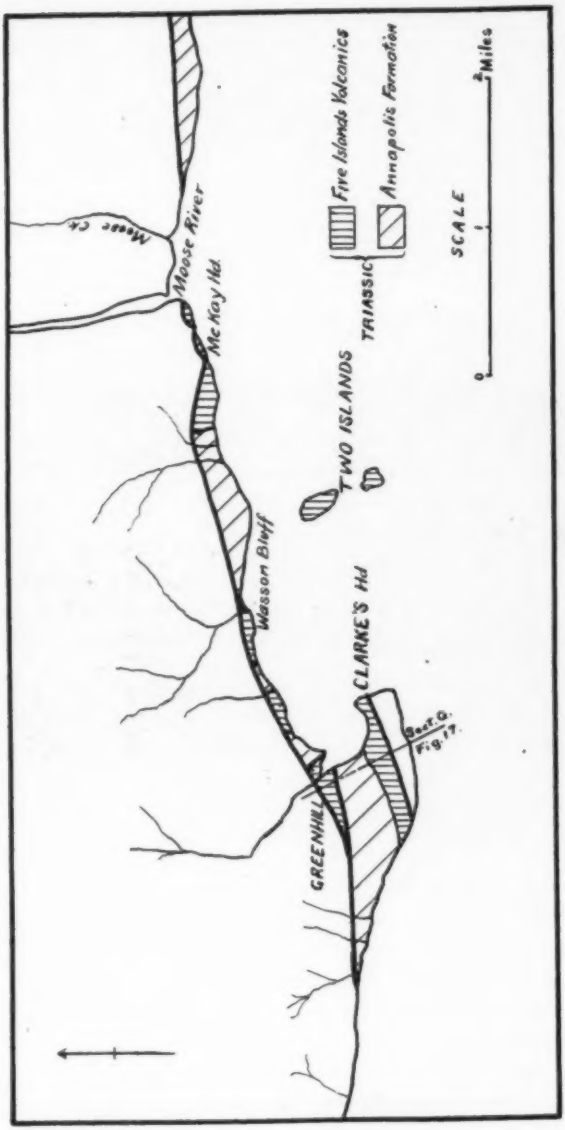

FIG. 15.—Map of the Two Islands region

5°–10°. The shale and sandstone underlying the basalt are exposed on the northeast side, for a short distance only. The sandstone

FIG. 16.—Structure section, G, through Clarke's Head, on the south, and Swan Creek, on the north. The structure of the pre-Triassic rocks is not shown. Overlying the Triassic red sandstone is a bed of tuff, overlain, in turn, by agglomerate. At Swan Creek only agglomerate appears, but it is probably a part of the same flow.

FIG. 17.—A detailed view of the agglomerate which comprises a large portion of the Five Islands volcanics. The photograph shows the center of a 100-foot bed of the agglomerate east of Blue Sack. The angular blocks are composed of basalt, and the matrix is tuffaceous.

is seen to be in fault contact with the Carboniferous shales and sandstone to the north.

Partridge Island.—East of Cape Sharp is a peninsula called Partridge Island, formed of a mass of basalt connected with the

shore by a low, swampy area which is covered by the sea at very high tides. On the northwest is Gilbert's Cliff, rising to a height of 60 feet, and on the northeast Parrsboro Pier (Fig. 13).

The basalt on Partridge Island (Fig. 14) is partly columnar and partly vesicular. It probably consists of two flows. Stilbite is very abundant in geodes in the amygdaloid. At the base of the lower flow the highly weathered amygdaloid is 15 feet thick.

The Triassic shales and sandstones are seen underlying the basalt on the west side of the island, dipping southward at an angle of 10 to 35 degrees. Near Gilbert's Cliff are red clays of Recent age, overlying the beveled, upturned edges of the ripple-marked Pennsylvania shales. The Triassic is not exposed to show whether this surface was the one on which the Triassic was deposited or whether it was the one made by the Pleistocene ice-sheet.

Greenhill–Five Islands.—From a point 3 miles east of Parrsboro, near Greenhill, to Five Islands, there is an almost continuous strip of Triassic, faulted down against the Riversdale–Union series of Pennsylvanian age (Fig. 15). The entire region has suffered extensive faulting and, with these movements, gypsum veins have been introduced.

The Newark comprises red sandstones and some shales, with occasional beds of green sandstone or shale; tuff and agglomerate beds; and basalt flows. The distribution of these rocks is very irregular, owing to the faulting, and is disturbed by extensive landslides in the volcanics.

FIG. 18.—Structure section from Moose Creek toward Blue Sack, a distance of about 2 miles, showing the character of the folding and faulting in the sediments as seen in the shore exposures. The height of the cliffs is 150–200 feet. On the extreme right, a bed of agglomerate of the Five Islands volcanics is shown, overlying sandstone.

West of Clarke Head is an excellent exposure showing sandstones overlain by black ash, and this by agglomerate, the whole being cut off by a fault (Fig. 16). North of Clarke Head, agglomerate is exposed, and copper has been sought at this locality.

East of Swan Creek, sandstone appears, overlain by a volcanic conglomerate—a mass of fragments 6 inches to 2 feet in diameter, of various kinds of basalt and agglomerate, imbedded in a red sandstone matrix. Above this, with a gradual transition, comes a true agglomerate of angular blocks imbedded in a tuffaceous matrix (Fig. 17). Sandstone appears above the agglomerate, and the contact is locally cross-cutting.

At Wasson's Bluff, agglomerate appears above red sandstone, with a conformable contact. East of Wasson's Bluff the agglomerate rests unconformably on the sandstone. Another local unconformity is found at McKay Head, where the sediments are overlain by agglomerate with columnar basalt above. East of McKay Head are two remnants of the same basalt, with faulted contacts. The cross-cutting nature of some of the contacts may indicate volcanic vents.

Two Islands, known also as The Brothers, consist of basalt flows dipping gently northwest. The islands are probably separated from each other and from the mainland by faults.

East of Moose River the sediments reappear and extend from this point around Minas Basin, continuously as far as the Shubenacadie River. The structure of the sandstones between Moose River and Five Islands may be seen in Fig. 18. Near Blue Sack (see Fig. 19) they are greatly slickensided, as shown in detail in Fig. 20.

On the top of the cliffs east of Moose River, tuff, overlain by agglomerate, forms a capping for the sandstone. The thickness of the volcanics varies, but is only 100 feet at a maximum. Near Blue Sack are two beds of agglomerate interbedded with sandstone, the lower being 100 feet or more, the upper 20 feet, with 10 feet of intervening sandstone. One of the contacts is cross-cutting, but there can be little doubt that the volcanics were formed contemporaneously with the sandstone, as blocks of basalt occur in the latter.

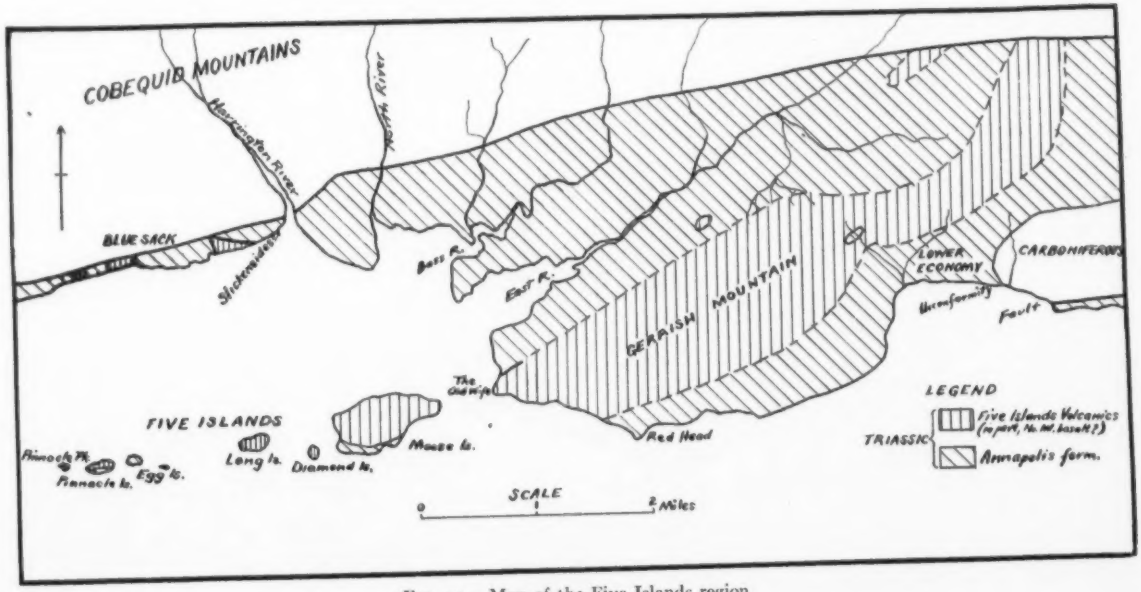

FIG. 19.—Map of the Five Islands region

This strip of Triassic is bounded on the north by a fault which probably continues east almost as far as Truro. The fault may be seen near the town of Two Islands, and between Moose Creek and Blue Sack the older rocks may be seen in one place at the top of the cliffs, in contact with the Triassic volcanics.

FIG. 20.—A detailed view of the slickensides north of Long Island of the Five Islands. The polished surfaces strike at right angles to the beach and the movement has been horizontal. Little or no vertical displacement is shown, but the slickensided surfaces strike toward the Five Islands between each of which there is a fault. It is impossible to determine which are the major fault-planes.

Five Islands.—The Five Islands are situated west of Gerrish Mountain. Their names, from east to west, are: Moose, Diamond, Long, Egg, and Pinnacle islands, and Pinnacle Peak (Fig. 21). Moose Island is nearly a mile in length and half a mile in width. The highest point on it is 350 feet above sea-level. Diamond Island is a small, round island, Long Island is one-quarter of a mile long and 180 feet in height at the center. Egg Island is smaller

and round. Pinnacle Island is a quarter of a mile long and 130 feet in height in the center. Pinnacle Peak is merely an erosion pinnacle. East of Egg Island at ebb tide is Egg Rock. At low tide, with a high run of tides, the sea-bottom between the islands and the mainland is left dry except for numerous deep river channels through the soft red clay.

Moose Island consists of basalt flows on the north, underlain by red sandstones on the south. On the west end there is a fault between red amygdaloid and the sandstone, with a number of gypsum veins near the contact. On the east side the amygdaloid and basalt above dip north at angles of 45° above the sandstone. At the base of the amygdaloid is greenish-white ash, 2 feet thick, similar to that at Gerrish Mountain. Fletcher's mapping of Moose Island and of the other Islands is largely incorrect.

Diamond Island consists of a portion of the same basalt flows as on Moose Island and the other islands. The dip of the basalt is about 40° northeast.

Long Island consists of basalt on the north and sandstone on

FIG. 21.—The Five Islands. On the left is Gerrish Mountain. The Five Islands are, from left to right: Moose, Diamond, Long, Egg, and Pinnacle islands, and Pinnacle Peak. Complex block-faulting separates these islands.

the south, with the contact striking nearly east and west. The dip of the sandstone and basalt is variable owing to minor folds, but is in general in a northerly direction about 20°.

Egg Island and Egg Rock on the east consist wholly of red sandstone, dipping northwestward about 15°. Pinnacle Island consists of red sandstone on the south and basalt on the north, dipping northwest at angles of 20°–40°. Pinnacle Peak consists of basalt.

Each of the islands is separated from the others by a fault, and they are probably bounded on the north by a continuation of the Gerrish Mountain fault. On each island the flows or sandstones dip northward, but at different angles.

The basalt flows of the Five Islands were undoubtedly originally connected with the flow on Gerrish Mountain and with those on the Two Islands. They do not, however, appear to be directly connected with the agglomerate and tuff which are exposed along the shore. Probably the dike in Gerrish Mountain was the source of most of the igneous material, part of which flowed out, and part of which was blown out. The relative age of the pyroclastic material and the flows could not be determined.

[*To be continued*]

AVERAGE REGIONAL SLOPE, A CRITERION FOR THE SUBDIVISION OF OLD EROSION SURFACES[1]

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Geological Survey of Canada

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SUMMARY

INTRODUCTION

During the four field seasons from 1908 to 1911 the writer was engaged in topographic and geologic work in the southern part of the Interior Plateaus of British Columbia. Certain questions which arose in the study of the physiography of that region are discussed in this paper.

Information regarding the physiography was acquired from a study of the Tulameen and Beaverdell map areas at the Southern end of the Plateaus, of the Kamloops and Shuswap[2] map sheets covering 9,000 square miles to the north of them, and from the

[1] Published by the permission of the Director of the Geological Survey of Canada.

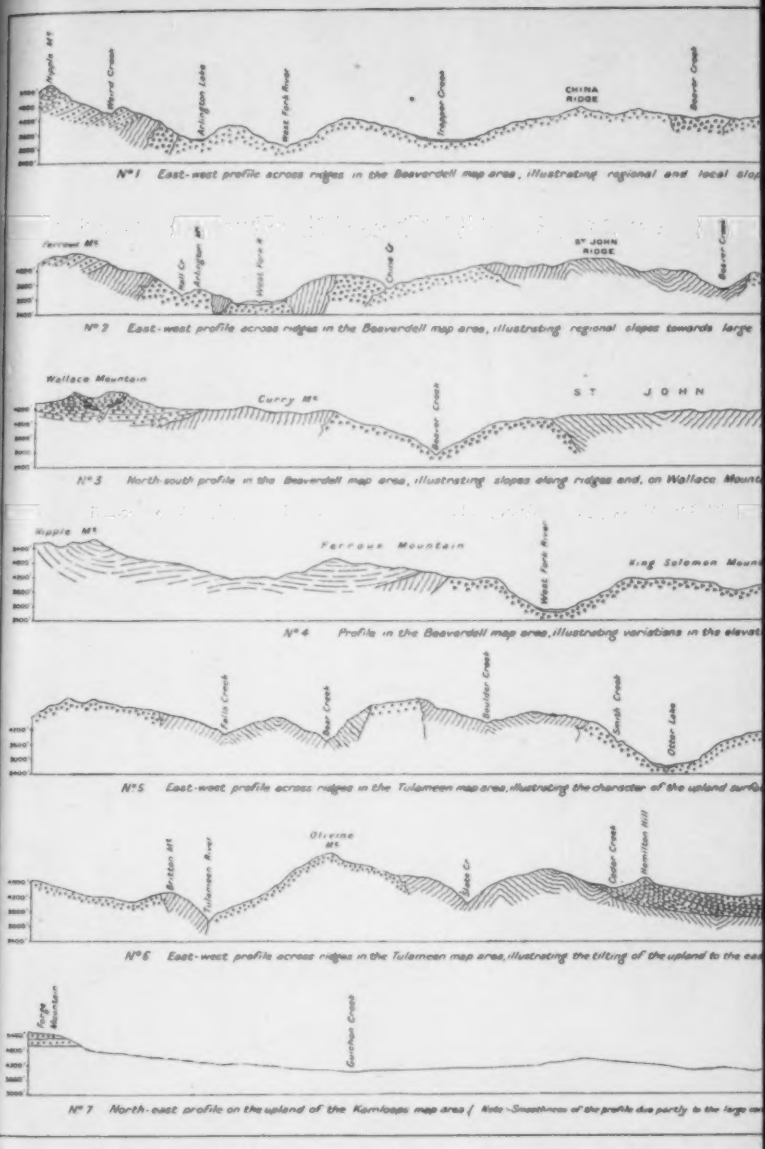
[2] The geological work upon the Tulameen map area was done by C. Camsell, and upon the Kamloops and Shuswap areas by G. M. Dawson of the Geological Survey of Canada. Explorations in the country between these areas have been made by the same men.

descriptions of the region lying between. The locations of the areas in question and of the Interior Plateaus are shown on the index map, Fig. 1. No detailed work has been done to the north of the Kamloops area, but explorations have indicated that the

FIG. 1.—Index map

character of the surface resembles that farther south although the general elevation is said to be less.

The southern part of the Plateaus consists of an old erosion surface or upland, dissected by younger deep valleys (Figs. 2, 3, and 4). The region appears to have been overridden by a conti-


Nº 1 East-west profile across ridges in the Beaverdell map area, illustrating regional and local slop
Nº 2 East-west profile across ridges in the Beaverdell map area, illustrating regional slopes towards large
Nº 3 North-south profile in the Beaverdell map area, illustrating slopes along ridges and, on Wallace Mount
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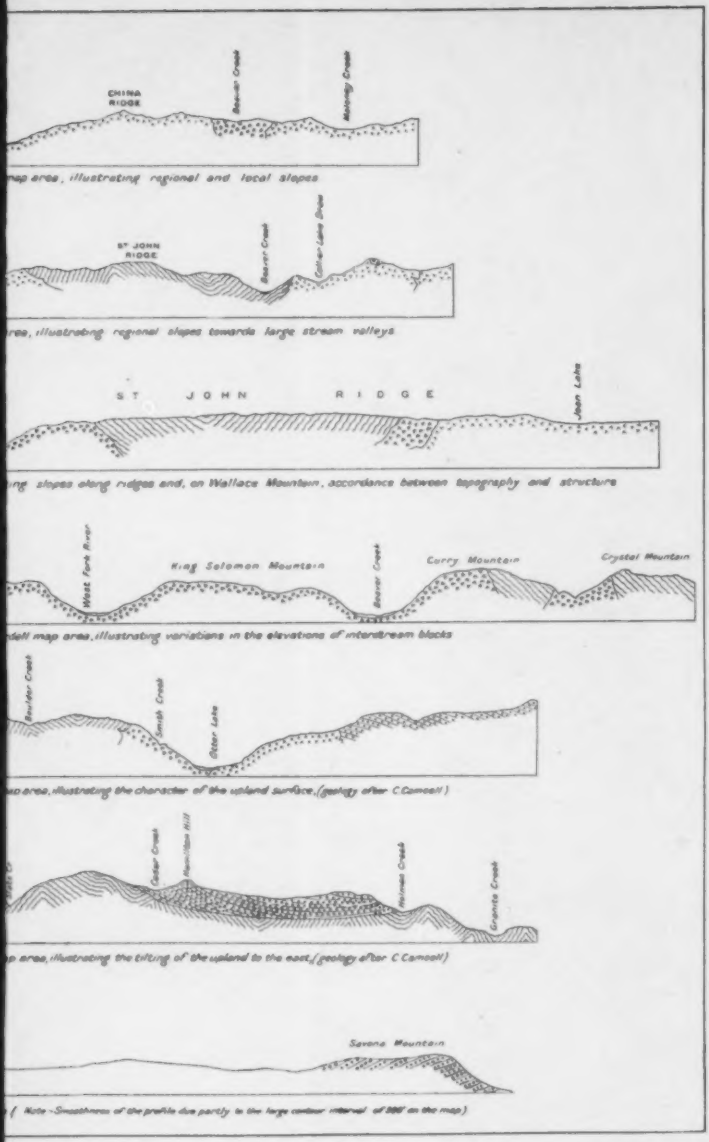
Nº 7 North-east profile on the upland of the Kamloops map area (Note:-Smoothness of the profile due partly to the large sc
CHINA RIDGE
ST JOHN RIDGE
Wallace Mountain
Curry Mt.
ST JOHN
Ferraux Mountain
King Solomon Mount
Olivine Mt.
Triassic Complex
Jurassic stocks and batholiths
Eocene batholith
Post-Oligocene batholith
Oligocene sediments

FIG. 2.—Character of the surface in the Interior Plateaus of British Columbia. F


CHINA RIDGE
Beaver Creek
Mahoney Creek
map area, illustrating regional and local slopes
ST JOHN RIDGE
Beaver Creek
Cottonwood Lake Drive
area, illustrating regional slopes towards large stream valleys
ST JOHN RIDGE
Joan Lake
ing slopes along ridges and, on Wallace Mountain, accordance between topography and structure
West Fork River
King Solomon Mountain
Beaver Creek
Curry Mountain
Crystal Mountain
detail map area, illustrating variations in the elevations of interstream blocks
Boulder Creek
Smith Creek
Otter Lake
area, illustrating the character of the upland surface. (geology after C. Camsell)
Cedar Creek
Hamilton Hill
Holmes Creek
Granite Creek
area, illustrating the tilting of the upland to the east. (geology after C. Camsell)
Savona Mountain
(Note - Smoothness of the profile due partly to the large contour interval of 200' on the map)
Post-Oligocene basalt, etc.
Oligocene sediments
Oligocene and Post-Oligocene lavas
River Alluvium

ior Plateaus of British Columbia. Horizontal scale: 1 in. = about 2⅔ miles

nental ice sheet which removed the soil covering from the upland, carved a few shallow rock basins, and left a thin irregular blanket of drift upon its retreat, but which does not appear to have modified the upland slopes in any essential manner. This old upland surface has all the essential characters which are commonly used as criteria to distinguish peneplains, but the average slopes on it, measured from the higher areas or ridges toward main drainage lines, vary from 150 to over 300 feet to the mile, and these slopes

FIG. 3.—View of a portion of the Interior Plateaus near the Tulameen Valley

are found on the surface as a whole, not merely on isolated portions of it.

If the slopes on this land form had not been measured, the dominant discordance of topography and structure and the general evenness of sky line would have caused it to be classed as a peneplain. The degree of slope present, however, led to a search for indications that would point to the fact that in this instance the stage of old age had just begun. It was found that the drainage system upon the upland was apparently related to a system of shear zones in the underlying rocks, and that in some of the areas underlain by certain Tertiary sediments and lavas, topographic form was governed by

geological structure. The accordance of topography and structure might in this case be described as a dimmed and accessory character, while the discordance was sharply defined and extensively developed, an essential character. It was found that on an old surface, with slopes of 3 to 6 per cent, the characters developed in maturity were just disappearing and those related to peneplanation were strongly developed but had not yet entirely supplanted the others.

According to the hypothesis of the geographic cycle this land form, if it had been left undisturbed, would have been gradually worn down; that is, its average slopes would have been gradually diminished, the characters of maturity have gradually disappeared, and the characters of peneplanation have prevailed everywhere. It seemed possible then, by using the criterion of regional slopes, to subdivide old land forms on a quantitative basis.

The primary object of this paper is to point out the importance of the measurement of average regional slopes upon "old erosion surfaces," and to show that such data assist materially in the more accurate study of the physiographic development of the region in which these surfaces occur, and of the diastrophic movements which have taken place there. The writer believes that it will be possible eventually to subdivide old land surfaces on the basis of their average slopes, and has attempted to do so here. The subdivision proposed is necessarily imperfect, partly because of the lack of accurate data regarding the slopes of old erosion surfaces, and largely because of the writer's imperfect knowledge of the literature describing such surfaces. As more data upon the slopes of old surfaces become available, however, the imperfections of a subdivision of this kind can be remedied.

METHOD OF MEASURING REGIONAL SLOPES

By regional slope is meant the general slope of the land toward main drainage lines. Slope is stated here as the percentage of vertical to horizontal distance rather than as an angle, because the measurement of the angles of slope on a land form of moderate relief is generally impracticable in the field, and for that reason the degree of slope stated as an angle, especially if the angle is small, does not

FIG. 4.—View of the Interior Plateaus looking northeast across the valley of the Tulameen River

carry a suggestion of the actual land form to the mind of the reader. For the measurement of such slopes either topographic maps or a number of traverses across the region to be examined are essential. An appreciation of the significance of the slopes can, however, be attained only by traveling over them.

The following is an outline of the methods followed in obtaining data from topographic maps of portions of the southern section of the Interior Plateaus of British Columbia. These methods were applied, in part, to the measuring of slopes upon topographic maps of certain sections of the United States, with satisfactory results.

The first step to be taken is the drawing of a number of profiles, some in the direction of the main drainage and others at right angles to it. The profiles should include as many of the pertinent topographic features of the region as possible. If they are plotted with a vertical scale somewhat larger than the horizontal, they will assist both in determining whether the land form under consideration is the result of one or more cycles of erosion, in discovering whether processes other than subaërial erosion have been responsible for existent forms, and in detecting tilting or warping of the crust subsequent to the formation of the surface. The usefulness of profiles is discussed more fully farther on. If forms due to more than one cycle are present, slopes should of course be measured on each of those forms separately. In the Interior Plateaus two cycles are represented, an older upland and younger valleys intrenched in it. There is a distinct break or topographic unconformity between the upland and the valley forms (Fig. 2, profiles 1 to 7). In this instance the measurements of slopes on the older land form, the upland, were made by taking a large number of horizontal measurements on the topographic map from a dominant ridge line to the bottom of a large upland valley. If a deep valley of the younger cycle occupied the site of the bottom of the old valley, the measurements were made to the point where the break in slope occurred between the old and the young forms (profiles 1 and 2). Horizontal measurements were made as long as possible, and never less than one mile. The vertical difference was read directly from the topographic map. Measurements were taken in both directions

at right angles to the trend of the ridge, and also along its crest. Variations in the slopes along ridge crests in the Beaverdell map area of southern British Columbia are illustrated in Fig. 2, profiles 3 and 4. The average slope measured on four or five ridges in this area lay between 100 and 300 feet to the mile, and averaged over 200 feet except in places where certain Tertiary formations occurred over which the slopes ranged between 500 and 900 feet to the mile, and averaged 600. The Tertiary areas occupied less than one-eighth of the area of the whole upland; the average slope along ridges therefore averaged between 200 and 300 feet to the mile. Slopes across ridges were in this area of very nearly the same magnitude and did not average over 300 feet to the mile.

Slopes as high as 900 to 1,000 feet to the mile were found in a few places only, and could have been omitted from the general average without changing the result to any great extent. Such local irregularities of slope are more likely to occur in land forms with fairly high slopes than in those which are of a plainlike character. Of twelve measurements on the Caldwell, Kansas, map sheet for instance, six lay between 14 and 21 feet to the mile, four between 32 and 35 feet, one was 47 feet, and one 10 feet to the mile.

VALUE OF THE MEASUREMENT OF REGIONAL SLOPES

The study and determination of the regional slopes upon old erosion surfaces is both useful and necessary. It is useful: (*a*) in helping to determine the agencies which have carved and molded the topography to its present form, and (*b*) in separating forms due to different erosion cycles. It becomes necessary (*c*) when an old erosion surface is to be used as a datum for measuring diastrophic movements.

a) The study of regional slopes often will indicate the agencies which have carved or assisted in carving a land form. This is illustrated by Barrell's[1] work along the New England coast. He found that certain flat-topped ridges in the interior sloped gently toward the coast, and the plainlike surfaces, of which the ridge tops were residuals, occurred in terraces of successively higher

[1] Joseph Barrell, "Piedmont Terraces of the Northern Appalachians," *Bull. Geol. Soc. Am.*, XXIV, No. 4 (December, 1913), 688–90.

elevations, each being separated from the next by a shorter and steeper slope. Further study proved that a number of flat hilltops in this region, which have for a long time been regarded as residuals of a tilted peneplain formed by subaërial erosion, were in reality parts of a series of wave-cut marine terraces.

b) The measurement of slopes and the study of profiles were found very useful in determining the number of cycles of erosion through which the uplands of the Interior Plateaus of British Columbia had passed. The older uplands and younger valley cycles were separated with comparative ease, but detailed study of the slopes was needed to show that no remnants of an older plainlike surface existed within the upland itself.

c) The measurement and recording of regional slopes will be of the greatest value, however, in cases where old surfaces and their residuals are used to determine the manner in which earth movements have taken place or the amount through which a section of the crust has moved. The manner in which movements of the crust have taken place sometimes can be brought out by profiles (see Fig. 2, profile 6), but it is necessary to determine the original internal relief and average slope of an elevated or warped old erosion surface before such a surface can be used for quantitative measurements of movements of the earth's crust.

In the uplands of the Interior Plateaus, for instance, the relative relief of points within 10 miles of each other quite commonly is from 1,500 to 2,000 feet. If such a surface be uplifted and dissected until only remnants of it remain, the difference of elevation between them could be 1,500 feet without the section of the crust within which they occur having been either warped or tilted. Calculations of earth movements based on the assumption that such a surface was plainlike before uplift would be liable to errors of 1,500 feet or more. If the slopes are not measured, however, old surfaces of marked relief are likely to be thought nearly flat or of much lower relief than actually is the case. For instance in describing an old erosion surface in the Colorado Front Range, Davis[1] says: "In the highland west of Palmer Lake, between Denver and Colorado Springs the sky line seems to be essentially

[1] W. M. Davis, "The Colorado Front Range," *Ann. Assoc. Am. Geog.*, I, 42.

level; much more so in the actual view than would be inferred from the crowded contours of the Platte Canyon map sheet."

Value of certain criteria of peneplanation.—The reasons for mistakes of the kind referred to are, first, that an uplifted old erosion surface of moderate relief is often seen in juxtaposition to younger topographic forms upon which the slopes are much steeper, so that by contrast the relief on the older surface appears much less than it really is.

A second and less obvious reason is that certain of the more important characteristics of plainlike erosion surfaces with average slopes of less than 10 feet to the mile are found also on old erosion surfaces with slopes as high as 300 feet to the mile. The criteria referred to are a general flatness of sky line and the planing of a rather flat topographic surface across rocks of different hardness and texture without any apparent change in the character of the topography.

Flat sky lines: In a rolling hill country ridge lines sloping from 100 to 300 feet to the mile may appear quite flat and the completeness of the illusion will depend partly on the position of the observer and partly on the distance of the ridge line or lines from him. Flat sky lines often are caused by the blending of more than one ridge line of entirely different elevation in the observer's line of sight, the irregularities of one being neutralized by the other (Figs. 3 and 4). The writer knows of at least one locality in the Beaverdell map area of British Columbia where an observer, climbing up one side of the West Fork River valley and looking across to the opposite side, would see first a flat sky line on a ridge with an elevation of 4,000 feet, and as he climbed higher another flat ridge line would come into view with an elevation approximately 700 feet higher and lying 3 miles farther away. The two ridges are shown in cross-section in Fig. 2, profile 2, the flat top of the higher, the St. John ridge, in profile 3. Between the two positions there is doubtlessly one where both ridge lines would blend and appear as one. The flat sky line in this instance evidently does not mean that the ridge tops represented in the sky line are remnants of one nearly flat plain, for the lower one is next to a large river, the higher 3 miles from it, and the slope between them over 200 feet to the mile.

Nor can the lower and flatter of the two ridges be considered a peneplain remnant. Both ridges are, in fact, part of one surface in the stage of early old age, a surface with average slopes of about $2\frac{1}{2}$ per cent. Their nearly flat surface is doubtlessly due to their lying between nearly parallel drainage lines.

Measurements made along apparently flat ridges, moreover, often show that they slope at a quite appreciable rate. The slopes upon St. John ridge, one of the ridges referred to in the preceding paragraph (Fig. 2, profile 3), vary from 100 to 300 feet to the mile. In Fig. 4, an apparently flat sky line is shown between the points *a* and *b* which are about $7\frac{1}{2}$ and 6 miles respectively, from the camera. From the photographic work done at this place it is known that a vertical shift of $\frac{1}{100}$ of an inch in the sky line of the picture represents an actual fall of 90 feet in the topography, and that between *a* and *b* there is a broad upland draw which is 250 feet deep, and whose sides slope at the rate of 100 feet to the mile. If the sky line in Fig. 4 were farther away, it would, without doubt, appear much flatter. In the clear western air, ridges 20 miles away often are plainly visible.

Discordance of structure and topography: Discordance of topography and structure must also not be considered a final proof that the land form being examined is at all plainlike. Relatively flat surfaces planing across the contacts of rocks of different hardness are quite common in the Interior Plateaus, but sloping surfaces which plane across the structure are much more common. The flat areas are local developments on the rolling-hill type of Interior Plateau topography. In one instance a flat surface was seen planing across a centroclinal basin of relatively soft rocks which were protected on the outside by hard layers. The flat surface is shown in Fig. 2, profile 6, just east of the point marked Hamilton Hill, and a part of the same surface in the foreground of Fig. 4. This is undoubtedly a case of local base-leveling and not a proof of universal peneplanation. In another locality a flat ridge top lying next to a large river at an elevation of 3,800 feet was found planing across the structure. The ridge, a part of King Solomon Mountain in the Beaverdell area, is shown in cross-section in Fig. 2, profile 4, but the change of structure is not shown in the profile. This ridge

top represents the lowest part of the upland within an area of several hundred square miles and within 10 miles of it there are numerous ridges from 1,000 to 2,000 feet higher. The flat surface is a small but integral part, not of a plainlike, but a decidedly hilly, land form. Discordance between topography and structure is, moreover, as well developed on the sloping hillsides of that land form as on the few flat surfaces that are present within it.

Neither approximately even sky lines, nor flat or nearly flat areas planing across the structure, are therefore in themselves a proof that the land form within which they occur is of more moderate relief than the upland of Interior Plateaus with average slopes as high as 6 per cent. The measurement of the slopes on old erosion surfaces must therefore be made before one can venture to judge of its actual relief or use it in quantitative measurements of earth warping.

PROPOSED SUBDIVISION

The following subdivision is concerned only with the stage of old age in the normal cycle of erosion as outlined by Davis.[1]

An old erosion surface is for the purposes of this discussion defined as a geographic unit worn down by subaërial processes alone to a state of moderate relief. By geographic unit is meant a portion of the earth's surface over which topographic conditions and the underlying rock structure were essentially similar at the beginning of the erosion cycle, and over which conditions of erosion remained essentially the same while the cycle was in progress. It is proposed to treat all surfaces in this stage as varying from two types, those of plainlike forms of peneplains and forms corresponding in general features to the uplands of the Interior Plateaus of British Columbia which may be referred to as "beveled hills." Following Smith[2] and Davis[3] peneplains are defined as geographic units worn down by subaërial processes alone to a condition of very moderate relief. The theory of the formation of such plainlike land forms does not necessarily imply that all parts of them lay

[1] W. M. Davis, "The Geographic Cycle," *Geog. Jour.*, XIV (1899), 481.

[2] W. S. Tangier Smith, "Some Aspects of Erosion in Relation to the Theory of the Peneplain," *Univ. of California Bull. Dept. of Geol.*, II (1899), 155–77.

[3] W. M. Davis, "The Geographic Cycle," *Geog. Jour.*, XIV (1899), 486.

near the ocean at the time of their formation. If the geographic unit be large, parts of it must lie far from the ocean and may be at a considerable elevation above it.[1] The "Almost plains" are characterized as presenting absolute discordance between topography and structure, graded streams and hill slopes, that is, practically a lack of cliff and local flat surfaces, and by deep soil covering. These are the commonly accepted criteria for determining peneplanation. In addition, we suggest that the term be restricted to surfaces with average slopes of less than 2 per cent, 105 feet to the mile. For examples of peneplains one may cite the Laurentian peneplain[2] of Canada, and a peneplain in the Mississippi Valley illustrated by the Caldwell, Kansas, topographic map sheet.[3] The Laurentian peneplain has an area of about two million square miles, with average slopes of about one-tenth of 1 per cent. It differs from an ideal type in that it has been modified by the accident of glaciation in removing the residual soil, in substituting an irregular drift mantle, and in slightly altering the form of the original surface. Upon the Caldwell area, average slopes vary from 10 to 50 feet to the mile, that is from one-fifth of 1 per cent to 1 per cent.

"Beveled hills" are characterized as geographic units worn down to moderate relief by subaërial processes alone. Their "essential" characters are discordance of topography and structure, graded slopes, smooth sky lines and contours, and a deep soil covering. Their "accessory" characters are local accordance between topography and structure, and the local occurrence of cliff faces and flat areas, that is, of ungraded slopes. In this instance the terms "essential" and "accessory" are used in the same way as they are in petrography, essential characters being those which predominate within the land form, accessory those of which but few examples can be found and which may be entirely absent.

"Peneplains" and "beveled hills" are distinguished therefore by their degree of slope and also by the occasional finding in the

[1] W. M. Davis, "The Colorado Front Range," *Ann. Assoc. Am. Geog.*, I, 42.

[2] A. W. G. Wilson, "The Laurentian Peneplain," *Jour. Geol.*, XI (1903), 628–29.

[3] Henry Gannett, "Topographic Atlas of the United States. Physiographic Types," *U.S.G.S.*, Folio 1, Caldwell, Kansas, sheet, 1898.

"beveled hills" type of characters which are characteristic of the stage of maturity.

It is suggested that the upland portion of the Interior Plateaus of British Columbia be taken as a type of the "beveled hills" form, and that the term therefore be restricted to old erosion surfaces upon which the average regional slopes are from 3 to 6 per cent. The upland of the Plateaus differs from an ideal type in that glaciation has removed the soil covering and substituted an irregular mantle of drift.

The term "beveling" was introduced into physiographic literature by Tarr.[1] He applied the term to the process of the cutting down of certain of the peaks and ridges on a land form, by differential erosion, to approximately uniform elevations. According to Murray's *New Dictionary* one of the meanings of "to bevel" is "to reduce (a square edge) to a more obtuse angle." As used in this paper the adjective "beveled" is meant to suggest that the land form so designated has been reduced to one on which nearly uniform sky lines are a common characteristic, and one upon which ridge tops have broadened or become rounded in cross-section; that is, the angles which ridge sides make at their crests have been increased to obtuse angles. "Hills" are meant to suggest that the land form is composed of numerous eminences of moderate relief and of smooth and rounded contours. Except in so far as it suggests reduction from a higher and more rugged form, the term "beveled hills" is intended to be descriptive, and is not meant to suggest the agencies by which reduction was effected.

GENETIC SIGNIFICANCE OF REGIONAL SLOPES

The desirability of a subdivision of this kind is that it will stimulate the gathering of data on the slopes of old erosion surfaces, and that it places definite limits on the term "peneplain." The value of such data and of such a restriction have been referred to before. An added argument in its favor is that the subdivision is based upon a factor which is of genetic significance in the development of land forms. For the slopes of a topographic form are not only one of the results of its development, but the amount of slope

[1] R. S. Tarr, "The Peneplain," *Am. Geol.*, XXI (January–June, 1898), 351–70.

present is also a factor in the rate of its further development. Moreover, the rate of development decreases so rapidly with decrease of slope that "beveled hills" are probably chronologically closer to forms in early maturity than to peneplains.

It is proposed in the following section to give proofs for the hypothesis that the rate at which a land surface progresses through the geographic cycle is dependent on its average regional slope, and that its progress becomes slower as the slopes become less. This hypothesis has of course been accepted by physiographers[1] for a long time, and is discussed only because of the emphasis placed in this paper on "average regional slope" and because the writer has found no presentation of evidence to prove this hypothesis.

The products of erosion in the normal geographic cycle are practically all removed from the land by streams. The rock waste is moved downstream partly as débris and partly in solution, and, if one could compare the amount of load carried by the streams on any land form during two stages of its progress, when average slopes were known, a measure would be furnished of comparative changes in the rate of erosion as the geographic cycle progresses toward old age.

The load consists of débris dragged along the stream bed, débris carried in suspension, and rock matter carried in solution, each of which will be considered in the order named.

A series of experiments have been made by Gilbert[2] on the relations between the load of débris that a stream can drag along its bed, and its slope.

The experiments proved that the quantity of load dragged by a stream varies in a complex manner with a set of controlling factors—such as slope of stream bed, discharge of water per second, fineness of débris, and form of stream channel. The changes, in amounts carried, vary at a different rate for each of the factors concerned. Under the conditions of the laboratory, the load dragged along the stream bed varied with the slope, but at a greater rate.

[1] W. M. Davis, "The Peneplain," *Am. Geol.*, XXIII (January–June, 1899), R. S. Tarr, "The Peneplain," *ibid.*, XXI (January–June, 1898), 354, 365.

[2] G. K. Gilbert, "The Transportation of Débris by Running Water," *U.S.G.S., Professional Paper No. 86*, pp. 10–54, 120, 121.

If, for instance, the slope, expressed in percentage of fall to horizontal distance, was doubled, the load dragged was, in the experiments, increased three to more than tenfold. Conversely as the slope decreased, the load decreased, but at a greater rate.

The load carried in suspension is partly a function of the stream's velocity, and depends partly upon the fineness and amount of débris supplied. In experiments made on streams without load, the velocity was found to vary approximately as the 0.3 power of the slope, and the 0.25 power of the discharge.[1]

The size of pebbles which can be carried in suspension varies as the fifth power of the velocity; that is, if velocity were unaffected by the addition of débris, it would vary approximately as the $\frac{5}{3}$ power of the slope. Velocity is diminished by suspended matter, but not enough to make the factor of $\frac{5}{3}$ less than unity. It is probable that in the majority of cases the grading of débris supplied to a stream is such that, if the slope be increased, the maximum load of suspended material carried by a stream will increase at a rate comparable to the rate of increase of the size of débris carried; that is, it will increase at a slightly greater rate than the increase in slope. Conversely if the slope be decreased, the maximum load carried in suspension will be decreased but at a greater rate than the slopes.

If discharge and fineness of débris supplied remain the same, therefore, both the maximum load dragged along a stream bed and that carried in suspension decrease at a greater rate than the slope, and the difference in the rate of decrease of the two functions becomes greater as the slopes decrease. This law of variation is applicable to natural streams as well as to those in the laboratory.[2]

But changes in discharge and fineness of débris as old age progresses, both tend to reduce further the load carried. For the rainfall on a land form, the size of a geographic unit is likely to decrease as the land becomes lower, and the proportion of runoff to rainfall will also decrease so that the discharge of the streams would decrease. The débris supplied to the streams, moreover, becomes

[1] *Ibid.*, 225. Discharge is defined as the number of cubic feet of water passing a given point per second.

[2] Gilbert, *op. cit.*, p. 233.

finer with old age and its increasing depth of soil. But suspended matter added to a stream retards its velocity, and the rate of retardation becomes greater as the débris becomes finer.[1] Hence as the slopes became lower, both the factors of decreased discharge and increased fineness of débris would help to a further and more rapid rate of decrease of maximum load carried.

Obviously also the amount of creep and wash of débris down hillsides into the stream beds is smaller on gentle than on high slopes. The rate at which a land form is worn down by mechanical erosion must therefore diminish very rapidly as the slopes decrease. On the other hand, lower slopes may aid chemical erosion, in that more rain water is absorbed and the solution of the rock materials near the surface is increased. Chemical erosion must, however, be a very small factor in the wearing down of a land surface, for the matter dissolved in river waters is derived from surface rocks in the process of weathering, and the greater bulk of the rocks at the surface lose on an average less than one-third of their original weight by the process of solution when weathering is complete. Moreover, part or all of this loss is compensated for, both in weight and in bulk, by gains in the form of oxygen, water, and carbon dioxide obtained from the atmosphere, and recombined as insoluble mineral products in the residual soil.[2]

If the average slopes of a land surface, therefore, be reduced in the progress of the geographic cycle from, say, 4 per cent to 2, the rate of reduction of the land surface by erosion will be less than one-half what it was before, and as the slopes decrease, the process becomes slower and slower.

The final stages of old age in which the surface is reduced to slopes as low as one-tenth of 1 per cent must therefore represent a very much longer period of time than the stage of maturity or of early old age. Chronologically, therefore, "beveled hills" are probably closer to land forms in early maturity than to "peneplains," and for that reason alone the subdivision proposed in this paper should be justified.

[1] Gilbert, *op. cit.*, p. 228.

[2] F. W. Clarke, "The Data of Geochemistry," *Bull. 491, U.S.G.S.*, pp. 462 and 465.

OBJECTIONS TO A SUBDIVISION BY AVERAGE REGIONAL SLOPES

The objections which may be urged to a subdivision of this kind are: (*a*) that it is an arbitrary one; (*b*) that the slopes on a land form vary widely, and two observers may come to different conclusions regarding it; (*c*) that it requires a greater amount of detailed field and office work than is necessary when the average slopes are not taken account of.

a) The subdivision is arbitrary, for as far as we know there is no distinct change in the cycle at either of the two limiting points of 2 and 3 per cent, which is placed on the two type forms proposed here. Moreover, it is probable that there are old erosion surfaces to represent all stages of average regional slope from 6 per cent to less than one-tenth of 1 per cent, and there may be as many examples lying between the two types proposed as within the limits of the peneplain type.

A parallel might be drawn between the classification of igneous rocks and the subdivision proposed here. In 1886 or thereabouts, when geologists of the United States Geological Survey found large areas in the Sierra Nevada Mountains underlain by intrusive masses of approximately similar composition lying between the quartz-diorite and granite families, they suggested the name granodiorite for them. Thirteen years later Lindgren[1] proposed definite limits for the "granodiorite" family in regard to both its chemical and mineralogical composition. The bulk of the rock masses referred to in the Sierras, and later found to occupy great areas in Canada, fall within the limits proposed by him. His quantitative restriction of the term granodiorite is therefore justified, for it represents a natural group of rocks. The term gains stability, moreover, because of the occurrence of this group within a definite and accessible region.

This definition of granodiorite is of great value to petrographers because it furnishes a clear-cut standard of comparison and datum point within the scheme of classification. The occurrence of rocks intermediate in composition between granodiorite and granite on the one hand, or granodiorite and quartz-diorite on the other, does

[1] Waldemar Lindgren, "Granodiorite and Other Intermediate Rocks," *Am. Jour. Sci.*, IX (1900), 269–82.

not detract from the usefulness of the quantitative definition of the family, but rather adds to the necessity of such a definition. In the same way the term "beveled hills" proposed here represents a land form which actually occurs over the known portion of a large geographic unit, the Interior Plateaus of British Columbia, and the quantitative limits proposed for the type are those measured upon the land form in question. The value of the establishment of a subdivision centering about a quantitatively defined physiographic type should also not be seriously impaired by the occurrence of numerous intermediate forms.

b) The slopes on a land form vary widely, and an accurate average is not easily obtained. Variation in slope will cause trouble only in old surfaces of fairly high relief, that is, in the "beveled hills" type. In the work in the Interior Plateaus, it was found that the greater part of the surface within areas of about 200 square miles lay between 3 and 6 per cent, and where slopes of a mile or more in length varied greatly from the general average they occurred over small areas. By estimating the relation of the size of these areas to the whole, irregularities of slope were calculated into the whole, and found to change the general average very slightly. If care is taken first carefully to separate forms due to different cycles, and then to note the frequency of the occurrence of irregularities varying from the average, the final results will be found to be fairly consistent.

In land of lower relief, that is, in the peneplain division, the results will be found to agree much more closely for the variation in slope is very much less.

c) The amount of field work is greater than is necessary when slopes are not measured.

This is true even when the measurements are made on topographic maps, for in order to appreciate the meaning of the forms shown on a topographic map it is necessary that one examine them closely at first hand. The extra time and energy which physiographers will of necessity have to spend in traversing old land surfaces before they can obtain data upon the nature and extent of their slopes is one of the best arguments for the adoption of this classification instead of an objection to it. The geologist knows

that rocks must be cracked if results are to be obtained, and the physiographer who depends largely upon distant views will miss a great deal of the detail which helps to prove or disprove field hypotheses.

SUMMARY

In the study of the physiographic development of the Interior Plateaus of British Columbia, certain characteristics commonly accepted as criteria for peneplanation were found well developed upon an erosion surface with regional slopes of 3 to 6 per cent.

Stress is laid on the value of the study and measurement of the regional slopes of old erosion surfaces, and a quantitative subdivision of old erosion surfaces on the basis of their average regional slopes is suggested. Regional slope is defined as the general slope of the land toward main drainage lines, and an outline is given of the methods of measuring regional slopes, as followed in the work on the Interior Plateaus of British Columbia.

The determination of the regional slopes of a land form is of value in furnishing clews to the agencies which have affected its development, and in separating the products of the different cycles of erosion through which it may have passed. The measurement of regional slopes is essential if a land surface is used as a datum for the measurement of movements of the earth's crust. For if such measurements are not made, an uplifted old erosion surface is very likely to be considered of much lower relief than is actually the case. Such an assumption leads to serious errors in estimates of the manner and extent of movements of the crust. It is caused partly by optical illusions, and partly from the fact that the characteristic flat horizon lines and the discordance of topography and structure which prevail over old erosion surfaces of plainlike form are also found well developed upon surfaces of much greater relief.

It is proposed that old erosion surfaces be divided into two central types "peneplains" and "beveled hills." Peneplains are to be characterized by average regional slopes up to 2 per cent by discordance between topography and structure, by the absence of local irregularities of slope, such as cliffs and flat areas, and by deep soil covering.

"Beveled hills" are old erosion surfaces with dominant discordance between topography and structure, with a general absence of irregularities of slope, and with deep soil covering. In addition, one may expect to find on them the accessory characters of partial accordance between topography and structure and occasional cliffs and flat areas. It is proposed that the term be confined to forms with average regional slopes of from 3 to 6 per cent and that the upland portion of the Interior Plateaus of British Columbia be considered the type of this land form.

The subdivision is desirable because it will stimulate the measuring of regional slopes and thus assist in working out the physiographic development of the surface and diastrophic movements of the crust after its formation. It is not contrary to the accepted hypotheses of the genesis of a land form through the normal cycle of erosion, for the degree of slope is a factor in the manner, as well as the rate of development, of an erosion surface.

The objections to the subdivision are that it is arbitrary, that a true average of the regional slopes on a land form are hard to get, and that it involves more field and office work than are otherwise necessary. The objections are met in the following manner.

The type form "beveled hills" is represented by an old erosion surface, which is found throughout the southern portion of a large geographic unit, the Interior Plateaus of British Columbia. The subdivision is therefore not entirely arbitrary. The difficulty of obtaining a true average of the regional slopes on a land surface can be met by taking account of the relative area occupied by slopes departing from the general average. It is thought, finally, that the extra field work involved in traverses over the region will be of advantage in calling attention to details of physiographic interest which can be obtained in no other way.

It is well to repeat here that the object of this paper is first of all to point out the importance of the study and determination of regional slopes on old erosion surfaces, and that the particular form of subdivision proposed is not considered final.

CAIMANOIDEA VISHERI, A NEW CROCODILIAN FROM THE OLIGOCENE OF SOUTH DAKOTA

MAURICE G. MEHL
University of Wisconsin

In the summer of 1911, Mr. S. S. Visher, then connected with the Geological Survey of South Dakota, collected some interesting crocodilian material from the Oligocene of Washington County, South Dakota. Some time ago, the attention of the writer was called to these remains by Dr. Visher, and recently through the courtesy of Mr. W. H. Over, director of the museum at the University of South Dakota, the collection was loaned to the writer for study.

The material herein described consists of a goodly portion of a skull, a nearly complete mandible, two femora and other limb bones, a nearly complete series of vertebrae, many dorsal scutes, and numerous fragments. According to Dr. Visher, the collection was made from the Titanothere zone of the Lower White River beds, perhaps 20 to 30 feet above their base.

THE SKULL

Of the skull, nearly the entire right half is preserved as well as portions from the left side including the quadrate region, the posterior half of the cranium roof from the median line to the middle of the orbit and supratemporal vacuity, and fragments of the maxilla along the alveolar margin. Of the base of the skull but little remains save the separate occipital condyle and portions of the exoccipitals.

In general shape and appearance it is quite similar to that of the alligators. A lateral expansion of the maxilla in the region of the third to fifth maxillary teeth produces a marked break in the otherwise regular outline of the muzzle, more prominent, perhaps, than in most of the Crocodilia. The width of the skull in the region of this maxilla expansion is 72 mm. Immediately back

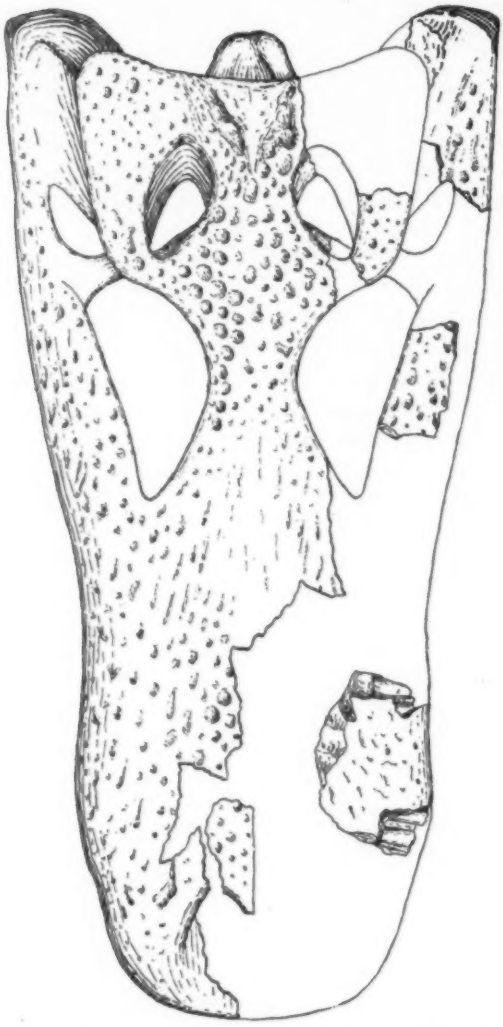


FIG. 1.—*Caimanoideus Visheri*, dorsal view of skull, about three-fourths natural size.

of the expansion, the width is but 66 mm. The greatest width, across the quadrates, is approximately 100 mm. The length of the skull, along the median line from the posterior border of the supraoccipital to the tip, is some 180 mm. From the posterior edge of the quadrates to the tip of the muzzle the measurement is 203 mm. Unlike the most of the Crocodilia, the inter-orbital region is flat, or essentially so, rather than presenting the marked concavity.

All the bones of the facial region of the skull are sculptured by more or less pronounced rounded pits or longitudinal grooves except the posterior ends of the nasals. In the maxillary region, the markings are more or less ill defined and, for the most part, take the form of long and narrow longitudinal grooves. The pits of the posterior frontal region are round, well defined, and deep. They are crowded close together and separated by narrow ridges only. The pits average 2.5 mm. in diameter, perhaps, in this region. On the jugals and squamosals, the

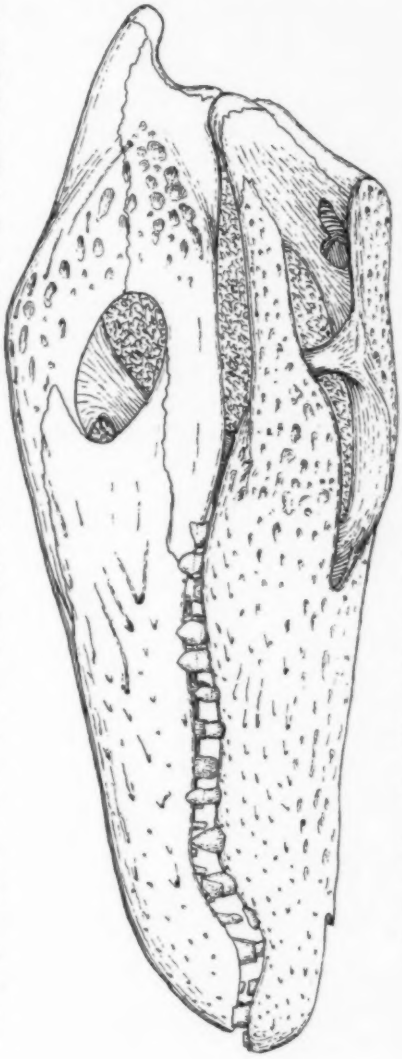


FIG. 2.—*Caimanoidens Visheri*, right lateral view of skull and mandible, three-fourths natural size

pits are shallow and varying in size, for the most part minute, but well defined.

The relations of the various bones of the skull are quite alligatoroid, as are their general proportions with few exceptions. The prefrontal is relatively longer than in the genus *Alligator* and extends at least half the length of the lachrymal in advance of the latter element. The nasals are relatively broad, the two making nearly half the total width of that part of the skull.

Unfortunately, part of the anterior border of the snout is missing, but the portions present are sufficient to show some of the important characteristics. Unlike the condition in all the true alligators, the nasals, while projecting slightly into the external narial opening, do not form a more or less complete bony septum. Furthermore, the premaxillae do not form an arch over the anterior border of the opening as is the case in all modern and extinct alligators with one or two exceptions, perhaps. In this respect, the skull simulates that of *Brachychampsa Montana*, an alligatoroid form described by Gilmore from the Upper Cretaceous of Montana.[1] To quote: "In the absence of a roof-like covering formed by the premaxillaries over the anterior part of the external nares, *Brachychampsa* differs from all known alligators, both recent and extinct."

The anterior border of the nares in the described form differs from that of *Brachychampsa*, however, in that the premaxilla in the former are still further reduced till the nares are directed slightly forward and lack entirely the definite ridgelike anterior border. This is the condition pointed out by Loomis in a specimen described by him from the Oligocene of South Dakota and referred to the genus *Crocodilus*.[2] Quoting Loomis on this point: "The undivided nasal opening is very far forward, and differs from that of the other crocodiles in the lack of a distinct anterior border, this portion of the nasal cavity having a smooth, rimless boundary on the premaxilla. The nostril opening would seem, therefore, to have been directed to the front, rather than upward on the snout.

[1] "A New Fossil Alligator from the Hell Creek Beds of Montana," *U.S. Nat. Mus.*, XLI (1914), 299.

[2] "A New River Reptile from the Titanothere Beds," *Am. Jour. Sci.*, CLXVIII (1914), 429.

(The lack of a rim gives the snout a distinctly mammalian appearance.)"

The teeth are well preserved for the most part and, with few exceptions, have the crowns preserved entire. On the right premaxilla, there are preserved four alveolae. On the portion of the premaxilla broken away, there is apparently space for two additional alveolae, but there is possibly only one. In the latter case, the total number is five, the number in the specimen described by Loomis. Concerning this series but little can be said, as only the circular roots of four remain. Of these the next to the last is the largest, 5.5 mm. in diameter. In each maxilla there are apparently thirteen teeth, a smaller number than is usually found in the alligators. Of these the fourth is much the largest, fully 8 mm. in diameter at the base and approximately circular in section. The posterior maxillary teeth are all more or less laterally compressed. The roots are oval in cross-section and in measurements range from 2.5 mm.×4 mm. to 4 mm.×7 mm., the more posterior teeth being the larger in general. The crowns of the first four maxillary teeth are somewhat flattened on the inner side and present a slight trenchant anterior and posterior edge. They are sharply conical and very slightly incurved, perhaps. The crowns of the posterior teeth show a rapid transition from this type to those with swollen crowns, rather sharply conical in the first of the series and more blunt or even of a rounded form posteriorly. A brief description of the well-preserved eleventh maxillary tooth will serve well to characterize this type. The crown is subglobular and is flattened somewhat on the upper, inner surface. It is sharply set off from the root by a marked necklike constriction. The apex is marked by an indistinct, antero-posteriorly placed carina that does not extend down on the sides.

Of the posterior part of the skull but little remains except the basi-occipital. The condyle is more or less spout-shaped and is divided into two distinct surfaces by a well-marked median groove.

The palate is almost entirely lacking except for a small portion along the maxilla-premaxilla union. At this point there is a deep, sharply outlined pit for the reception of the fourth mandibular

tooth. The pit does not perforate the facial surface of the bone, however, as is occasionally the case in the alligators.

The lower jaws are represented by an almost perfect right ramus and a goodly portion of the left, including the symphyseal and articular regions. The sculpturing of the mandible is much the same as in any of the alligators; the dentary is marked by small, deep pits and more or less prominent longitudinal grooves. In the region back of and below the external mandibular foramen the surface is dotted with deep rounded pits, irregular in size but distinct. In the relation of the various mandibular elements there is nothing of particular interest except perhaps in the unusual forward extent of the splenial. This element extends far forward and takes an ample part in the symphysis. Each ramus bears nineteen teeth, very similar, in general, to the maxillary teeth. The fourth tooth is the largest in the series, round in section, and measures fully 6 mm. in diameter at the base. The crown is largely missing, but was apparently sharply conical, and the indications are that there was a faint anterior and posterior carina extending down the sides. This was probably the condition of the anterior four teeth in each ramus. The root of the first tooth indicates that it was somewhat larger (about 4 mm. in diameter) than the two subequal teeth that follow.

Immediately following the fourth tooth is a series of seven, all comparatively short and slender and averaging about 2 mm. in diameter at the base and 4.5 mm. in height. These small teeth have slightly swollen crowns and a faint suggestion of anterior and posterior carina. The posterior eight teeth are subequal in size and quite like the eleventh maxillary tooth described above.

The nature of the bite is alligatoroid in that the teeth of the mandible all close within the teeth of the upper jaw and the fourth mandibular tooth fits into a deep socket in the palate surface.

THE VERTEBRAL COLUMN

Eight of the cervical vertebrae are present, all but the atlas. With the exception of the axis, they are all very pronounced procoelous. Although the union between the centrum and the arch is clearly distinguishable, the two parts are as a rule closely united.

There is nothing distinctive in this series that serves to set them off from the other Crocodilia save perhaps in the atlas. The odontoid process is very prominent, and in a superficial way resembles the spout-shaped process of some of the mammals. The total length of the series, allowing for the missing atlas, is approximately 18.5 cm. Of the dorsal series all are preserved. As the cervicals, they are of the pronounced procoelous type. The total length of the series is about 23.7 cm. The five lumbar vertebrae are well preserved. The posterior articular faces of the centra are all highly convex and round in outline except the fifth. In this the posterior face of the centrum is fully twice as wide as high. The lumbars together measure 11.7 cm. The two sacrals measure 4.7 cm. A noteworthy feature is the shifting of the sacral ribs. The posterior rib forms a small part of the posterior concavity into which the first caudal fits. The anterior rib is shifted forward to such an extent that it might be said to articulate intercentrally, for although it is solidly fused to the first sacral vertebra, nearly half of its diameter extends beyond the anterior face of that vertebra and articulates broadly with the last lumbar. Of the caudal vertebra, there are 23 preserved. There are probably about 11 missing, almost entirely from the posterior end of the series. The vertebrae present measure about 23.7 cm. To this should be added perhaps 16.5 cm. for those missing, making a total of 40.2 cm. for the caudal series.

Of the numerous appendicular bones indiscriminately preserved the femora alone, perhaps, deserve special mention. Both of these bones are nearly complete, but the right is the more nearly perfect (Fig. 3). The head is broad and much flattened. The articular surface extends entirely around the end and on the side of the pronounced rounded cone that rises from the concave lower surface close to the proximal end of the bone. The trochanteric ridge on the flexor surface is very pronounced, more so than usual. At this point, about 45 mm. below the head, the shaft is bent abruptly back and from there sweeps backward in a broad, anteriorly concave curve to the distal end.

The dorsal armor consists of a large number of pitted plates, sub-rectangular in outline for the most part. Of these there are

several distinct types and a great variation in size. All bear a more or less prominent antero-posteriorly directed carina on the dorsal surface and are concave below from side to side to some extent at least and often sharply so. The dorsal surface of all is deeply sculptured by small, rounded, closely crowded pits. While the anterior and posterior edges are smooth, the lateral edges of

FIG. 3.—*Caimanoideus Visheri*, right femur; *a*, from below; *b*, from above; *c*, from behind; three-fourths natural size.

most of them indicate a more or less firm union with an adjacent plate. In some plates, this union is indicated on one margin only, and a few apparently were entirely free. The plates were probably arranged in more or less rigid transverse rows of five units at least, and, in much probability, seven units for certain regions of the back. Fig. 4 indicates the apparent arrangement of the plates.

As pointed out above, the affinities of this form with the genus *Alligator* are marked. This is shown chiefly in that the fourth

mandibular tooth fits into a deep pit in the palate instead of closing in a notch, as in crocodiles. Furthermore, all the mandibular teeth close within those of the upper jaw. In the lack of a division of the anterior nares and the lateral union of the dorsal scutes, the form is quite similar to the genus *Crocodilus*. It apparently stands much nearer to *Caiman*, however, than to either of the genera mentioned above inasmuch as this group combines the alligatoroid bite, the undivided anterior nares, and the lateral union of the dorsal scutes. One of the striking differences from *Caiman* is to be seen in the entire lack of the anterior border of the external narial opening in the form here described. A new genus, *Caimanoeda*, is proposed to include this form *C. Visheri*, which may be considered the type, and *C. (Crocodilus) prenasalis*, Loomis,[1] a form that a careful examination of the type skull has shown to be very similar to *C. Visheri*.

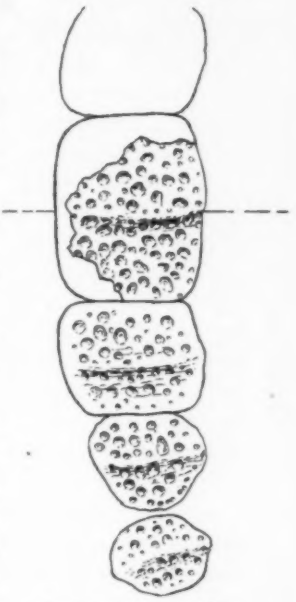


FIG. 4.—*Caimanoideus Visheri*, apparent arrangement of dorsal armor in transverse rows, about three-fourths natural size.

If one may depend on the figures of *C. prenasalis* there is a noticeable difference between the dorsal scutes of this form and those of *C. Visheri*. In the latter, all the scutes are more or less strongly keeled, and are much more finely and regularly pitted than in the former. Greater differences are to be noted in the vertebrae. Of the vertebral column of *C. prenasalis* Loomis says: "The vertebrae are all deeply procoelous. Those of the lumbar region have heads (posterior) which are short, wider than high, and rectangular in outline. Those of the dorsal region, however, are smaller and have prominent conical, rounded heads."

As pointed out above, in the lumbars of *C. Visheri*, the posterior face of the centra are regularly convex and round in outline and the

[1] *Op. cit.*

centra differ but little in size from those of the dorsals. The vertebra figured and described as a dorsal of *C. prenasalis* is apparently very similar to the anterior caudals of *C. Visheri* and may well belong to the caudal series. This being the case, the vertebrae of the two forms are not very different.

The remains of *C. Visheri* represent a creature approximately five and a half feet from tip to tip. The skeleton is probably not that of a young individual, but it is possible that it had not reached its greatest length. It is probably a good average for the species, and is apparently somewhat smaller than *C. prenasalis*.

While any record that indicates the former distribution, the relative abundance, and the diversity of the extinct Crocodilia is noteworthy, there is, perhaps, a special interest in the form here described in the light that it throws on the ancestry of the caimans. To the writer's knowledge, there is no record of extinct caimans and the history of the alligators is almost as obscure. While the genus *Caimanoidea* is perhaps too highly specialized in the external narial opening to stand in the direct line of the caimans, in other respects, especially the moderate size of the supratemporal fenestrae, it is very similar to what one would expect in their primitive ancestors. The genus stands close enough to the modern forms to indicate a very ancient history for this group.

The writer wishes to take this opportunity to thank Professor Over, through the courtesy of whom he was permitted to study the material here described, and President C. C. O'Harra of the South Dakota School of Mines for the loan of the type skull of *Caimanoidea* (*Crocodilus*) *prenasalis*. The writer is also greatly indebted to Professor Ruthven, director of the zoölogical museum, University of Michigan, for the loan of *caiman* material and for valuable information concerning that group.

The type of *Caimanoidea Visheri* is number 1,044 in the University of South Dakota geological collections.

ON THE STRUCTURE AND CLASSIFICATION OF THE STROMATOPOROIDEA[1]

M. HEINRICH

In the course of my studies on the numerous stromatoporids from the Rhenish Devonian which are in the Geological Institute of the University of Bonn, among them the types of Goldfuss and Bargatzky, I have come to hold a view concerning the structure and especially concerning the classification of the Stromatoporoidea which is not in harmony with the one now generally accepted.

Since the publication of my complete work, which will appear under the title, *Studien in den Riffkalken des rheinischen Mitteldevon. I. Teil: Biologie, Morphologie und Genesis der Riffe des rheinischen oberen Mitteldevon. II. Teil: Revision der Stromatoporen* is still somewhat distant, I will present here the results of the second part, leaving the detailed evidence to follow in the complete work.

It is apparent from all textbooks on paleontology and also from the often exhaustive works of recent students of this debatable subject (Parks and others), that since 1886–92 the view of Nicholson has been generally followed and the Stromatoporoidea therefore divided into two groups. The "milleporoid" group includes the forms which possess the so-called "zoöidal tubes"; and the other or "hydractinoid" group, those without such structures. To the first group are referred the families Stromatoporidae Nicholson and Idiostromidae Nicholson; to the second, the families Actinostromidae Nicholson and Labechidae Nicholson.

It now appears: (1) that the families Labechidae Nicholson and Idiostromidae Nicholson should be taken out of the order Stromatoporoidea, since their organization has scarcely anything in common with that of the remaining Stromatoporoidea. By means of this division, a simple, clear definition is obtained for the

[1] Translated from the German (*N. Jahrb. für Min.*, etc., 1914, No. 23, pp. 732–36) by Clara Mae LeVene, Peabody Museum, Yale University.

"true" Stromatoporoidea. (2) That the division into a "milleporoid" and a "hydractinoid" group must give way to another, since the distinction on which it rests is not present.

Next should be discussed the families which in my opinion have been incorrectly referred to the Stromatoporoidea, i.e., Idiostromidae Nicholson, with the genera *Amphipora* Schulze, *Stachyodes* Bargatzky, and *Idiostroma* Winchell, and Labechidae Nicholson, with the genera *Labechia* Edwards and Haime, *Rosenella* Nicholson, and *Beatricea* Billings.

In *Amphipora*, the old conception is to be replaced by that of Felix (1905), which I found confirmed in hand specimens from Letmathe and elsewhere in which the fossil had not yet been weathered out. According to this, around a non-tabulate axial canal, about 0.75 mm. wide, are grouped closed cells, which increase in size outward.

In *Stachyodes*, the original view of Bargatzky (1881) must be restored, which stated that from a non-tabulate axial canal there branch off non-tabulate lateral canals which in turn branch repeatedly. The wall structure of the canals is massive but seems to be perforated in places.

Idiostroma also has a non-tabulate axial canal, arising out of the openings, which bear apically calcareous interfingering lamellae. Otherwise the lamellae are only slightly perforated: They are supported at intervals by little walls and pillars. These are arranged more or less in the form of parabolas which extend from the apex backward. They leave between them a labyrinth of passages which also extend from the apex (the axial tube) backward. The passages of one and the same interlamellar cavity are well connected with one another, but seldom with those of the neighboring spaces, since the lamellae seldom show a pore.

In all three genera one misses the meshy structure as well as the astrorhizae of the "true" Stromatoporoidea, aside from the fact that these fossils never have a treelike appearance or anything like it.

Again, the skeleton of the Labechidae is not at all stromatoporoid, having no network of meshes open on all sides, but rather a complex of circular, closed, flat vesicles, which, according to the

genus, are broken through by pillars (*Labechia*), show reduced pillars on the convex side (*Rosenella*), or are free from pillars (*Beatricea*). Here is to be noted also, as an important negative characteristic, the absence of astrorhizae.

When, therefore, the families Labechidae and Idiostromidae are thus removed, the Stromatoporoidea no longer stand as a collective group of elements of unequal value, but the remaining "true" Stromatoporoidea represent a clearly limited order, for which the following definition may be given: The skeleton is built of seamlessly united, massive or porous calcareous fibers, which form a more or less regular network. In this can be recognized a more or less plainly layered arrangement of the tangential elements. Astrorhizae are always present.

From the examination of a greater mass of material it appears that in the skeletal structure of the Stromatoporoidea all transitional stages from regularly netted (reticulate) to markedly vermiform (vermiculate) are present. The division into a "hydractinoid" and a "milleporoid" group is incorrect, since it is founded upon a wrong supposition, for in none of the forms which were put into both groups are "zoöidal tubes" analogous to those of *Millepora* present. In fact, G. Steinmann in 1903 (*Milleporidium*, etc.) and W. Parks in 1909 (*Silurian Stromatoporoidea*, etc.), the former strongly, the latter at first doubtfully, questioned the so-called "zoöidal tubes."

A still sharper division into two groups lies in the fact that the relatively fine fibers of the family Actinostromidae are massive, while the somewhat thick fibers of the family Stromatoporidae show pores and little canals. On this ground a division of the Stromatoporoidae must rest.

This division principle: "Fibers massive"—"Fibers not massive" permits of an unquestionable division. Moreover, it is in harmony with the fact that in the massive-fibered group belong only entirely rectilinearly and altogether regularly built forms, while to the hollow-fibered group may be referred only those forms which are in some way irregularly vermiculate in their skeletal structures. The further division into genera rests in both groups on the degree of regularity of the skeletal mesh. It is, however, no

longer quite so sharp, since in many forms it is not certain whether they have a greater or less degree of regularity and so are to be referred to this or that genus. The differentiation into species is at best dependent upon the number of lamellae and pillars per millimeter, while the development of the astrorhizae and the tubercles, on account of their variability, comes into consideration only secondarily, and in extreme cases can only lead to the making of varieties.

It is especially to be noted in the work of Parks, who has recently published various studies on American stromatoporids, that often in one and the same specimen the conditions, e.g., the number of pillars and lamellae, vary so much that one cannot be too cautious in the making of new species, if the specimens are to be identified.

In accordance with the principles above stated, the following classification may be formulated:

A. Family Actinostromidae Nicholson. Fibers massive.
Radial and tangential elements equally well developed and united into a linear network (rectilinear). (Surface therefore granular.)
I. Pillars passing continuously through several lamellae: Genus *Actinostroma* Nicholson.
II. Pillars only one lamella high:
1. Lamellae quite flat: Genus *Clathrodictyon* Nicholson.
2. Lamellae strongly vaulted: Subgenus *Stylodictyon* Nicholson and Murie.

B. Family Stromatoporidae Nicholson. Fibers not massive (porous or perforate).
I. Radial and tangential elements equally strongly developed and plainly differentiated. Tangential section, however, in part vermiculate. (Surface therefore in great part granular, but in places vermiculate.)
1. Pillars passing through: ?Genus *Hermatostroma* Nicholson.
2. Pillars generally only one lamella high: Genus *Stromatoporella* Nicholson.
II. Radial elements somewhat rectilinear and strongly prominent as compared with the much thinner tangentials. Tangential section vermiculate. (Surface vermiculate.) Genus *Parallelopora* Bargatzky.
III. Radial and tangential elements equally strongly, very irregularly interlaced (vermiculate) and therefore no longer differentiated. Tangential and radial sections vermiculate. (Surface vermiculate.) Genus *Stromatopora* Goldfuss.

THE PHYSIOGRAPHY OF MEXICO[1]

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For one who approaches the study of Mexican physiography for the first time, it facilitates matters considerably to acquire in the very beginning a few fundamental concepts, particularly as regards the relations of the provinces of Mexico to those of the United States. We are likely to regard the Mexican provinces as ending abruptly on the north at the International Boundary, and at the south along an irregular political line separating Mexico from Central America. As a matter of fact, the Mexican physiographic provinces extend well into the United States, the natural northern boundary being in a general way the Pecos-Rio Grande, the escarpment of the Colorado Plateau, and the southern terminus of the Sierra Nevada Mountains. As thus bounded, Mexico, from a physiographic viewpoint, includes those provinces hitherto described for the United States under the names of Trans-Pecos Highlands, Arizona Highlands, and Colorado Desert.[2] The natural southern boundary is the isthmus of Tehuantepec. This excludes the states of Tabasco, Campeche, Yucatan, and Chiapas, but physiographically speaking, these political divisions belong to Central America rather than Mexico.[3]

All the topographic features included between these natural boundaries, with the exception of a narrow strip along the Gulf coast, may be traced back to a common feature which came into existence in early Tertiary time, and for which Hill has suggested the name "Cordilleran Peneplain."[4] This peneplain was made on the

[1] For complete bibliography see list of references compiled by me and published in *Mining Science*, LXX, Nos. 1745–47.

[2] N. M. Fenneman, "Physiographic Boundaries within the United States," *Ann. Ass. Am. Geog.*, IV, Pl. 1.

[3] E. Bose, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, XXXI, 15–16.

[4] R. T. Hill, "Growth and Decay of the Mexican Plateau," *Eng. and Min. Jour.*, LXXXV, 681–88.

closely folded Mesozoic sediments. The elevation of the peneplain made the great Mexican Plateau, which in its present condition may be described as a great tilted block, the up-tilted end overlooking the isthmus of Tehuantepec and the down-tilted end lying under the scarp of the Colorado Plateau and along the course of the Rio Grande.

On this plateau erosion and vulcanism have carved and molded a variety of topographic forms. The products of one or both of these factors characterize definite areas, and applying the definition that a physiographic province is an "area which is characterized throughout by similar or closely related surface features, and which is contrasted in these respects with neighboring areas,"[1] we find that the prominent topographic divisions of Mexico become its true physiographic provinces.

These provinces may be gathered for convenience in discussion into two groups: one, the northern, having a general north-south alignment, and the other, the southern, having a general east-west alignment (see accompanying map, Fig. 1). In order from east to west the members of the northern group are the Gulf Coastal Plain, the Anahuac Desert Plateau, the Sierra Madre Occidental, and the Sonoran Desert. Below these, in succession southward, come the Volcanic, the Sierra del Sur, and the Tehuantepecan provinces. Where province names are not self-explanatory, reasons for them will be given in the text to follow. In our discussion of the provinces we will begin with the Sierra Madre Occidental, for the reason that it is the oldest feature of Mexican topography and will aid in orienting us, so to speak, when we come to the discussion of younger features with more complex histories.

THE SIERRA MADRE OCCIDENTAL PROVINCE

Definition and boundaries.—The Sierra Madre has been defined as "a vast area of circumdenudation," "a higher island of summit survival,"[2] "a great plateau, fringed by mountains on the east, trenched by deep canyons in the center, and bordered by a wild and rugged complex of mountains on the west."[3] "It is not to be

[1] Fenneman, *op. cit.*, p. 87.
[2] Hill, *Eng. and Min. Jour.*, LXXX, 633.
[3] W. H. Weed, *Trans. A.I.M.E.*, XXXII, 444.

regarded as a single chain or mountain mass, but rather a group of chains, generally of the same orientation, successively rising, one

FIG. 1.—Physiographic Provinces of Mexico

1. Sierra Madre Occidental.
2. Anahuac Desert Plateau.
3. Sonoran Desert.
4. Gulf Coastal Plain.
5. Volcanic.
6. Sierra del Sur.
7. Tehuantepecan.

above the other, from west to east, separated by depressions of various widths and furrowed by streams of more or less importance."[1]

[1] E. Ordonez, *Inst. Geol., Mex.*, IV.

This province extends from near the International Boundary southward, roughly parallel to the Pacific coast, to the valleys of the Rio Grande de Santiago and the Rio Lerma. It has been suggested that the Chiricahua Range of Arizona may mark its former extent to the northward, and show the transition between it and the closely related province of the Colorado Plateau in the United States.[1] Throughout the greater part of its extent it will average 100 miles in width, but in the south it attains a width of 300 miles or more.

There are many Sierra Madres in Mexico; so many, in fact, as to be confusing to the casual reader of Mexican geography. The Sierra Madre Occidental, however, is the real "mother" Sierra, the progenitor of all the other Sierras in Mexico. If a section be drawn across Mexico from the Atlantic to the Pacific in almost any latitude, it will be found that every feature on the profile of that section, save a narrow strip of coastal plain, is related in some manner to this Sierra (see accompanying profile sketches, Fig. 2).

The northern boundary has been drawn at the International Boundary, where the Sierra Madre Occidental Mountains end rather abruptly and overlook the vast stretches of desert plateau to the northward.

The western boundary, from Naco, Arizona, to the mouth of the Rio Yaqui, follows the Rio Sonora and the Rio Moctezuma, which flow in structural valleys at the foot of the mountain scarp.[2] From Trinidad, Sonora, to the Rio Grande de Santiago, Tepic, this western line marks the highest escarpment overlooking the desert below, and is coincident with the state boundaries separating Chihuahua, Durango, and Zacatecas on the east from Sonora, Sinaloa, and Tepic on the west. There is no doubt that these boundaries between states are the result of natural selection, because the prominent topographic break makes an indisputable parting between political divisions. This line, which marks the present limit of the eastward retreat of the plateau, was determined by one of the prominent N. 45° W. fault lines which cut the plateau.[3]

[1] Hill, *Eng. and Min. Jour.*, LXXXIV, 631.

[2] See the Bartholomew map of Mexico, published by the National Geographic Society.

[3] J. D. Villarello, *Guides des excursions, 10th Inter. Cong. Geol. Mex., 1906*, No. 18.

The southern boundary of this province has been placed at the canyons of the Rio Grande de Santiago and the Rio Lerma; not arbitrarily, but because at this place there is a sharp change in the strike of the massive folded sediments.[1] North of this line the

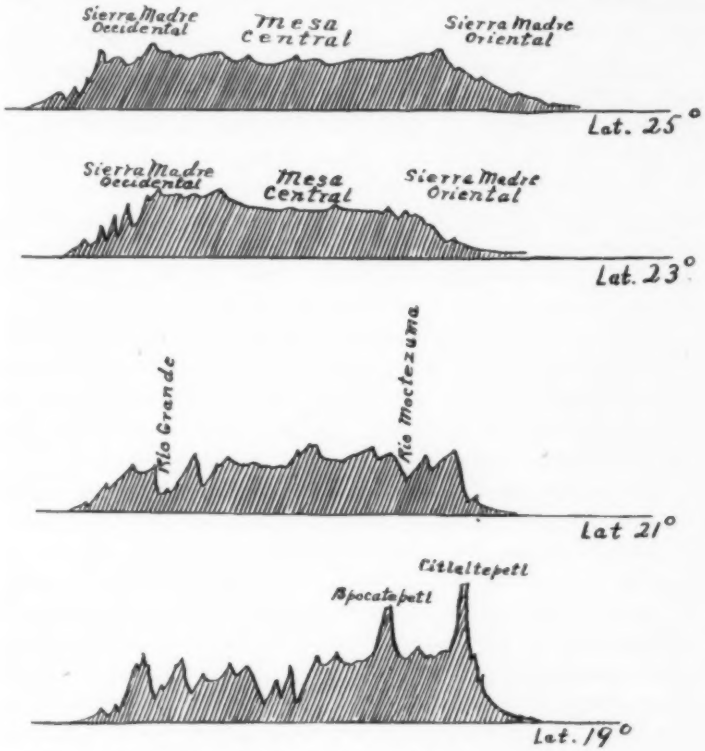

FIG. 2.—Profile of Mexican Plateau. (After J. G. Aguilera.)

structural trend is generally northwest–southeast, while south of it the trend is more nearly east-west. South of this line, also, erosional down-cutting in the plateau ceases to be the controlling factor in the making of the topography, and gives way to volcanic piling-up on it.

[1] Ordonez, *op. cit.*

The eastern boundary of this province begins at the International Boundary and runs in a general southerly direction through the states Chihuahua, Durango, Zacatecas, San Luis Potosi, and Queretaro to the Valle de Mexico. It is not a sharp line like the other boundaries of the province, but has been rather arbitrarily chosen throughout the greater part of its length, though not without certain criteria. It has been drawn to pass near such cities as La Junta, Parral, San Miguel, and Zacatecas, which are known to be situated at the eastern foot of the mountains. Between these cities the line has been drawn to pass through the points marking the sources of the small "suicidal" streams which rise near the border of the mountains and lose their small quantities of water by evaporation and percolation soon after reaching the desert below. The want of suitable topographic maps covering large areas makes a more accurate drawing of this line impossible. Its location cannot be far from correct, however, for it coincides with the line on the Willis geological map of North America, which separates the mountain country, where the volcanic cap rock is thick, from the desert to the east, where erosion has removed the extrusives and exposed the underlying Cretaceous sediments.

Topography.—In a general way the topography of this province may be described as "a succession of narrow and continuous northwest-southeast ridges, with foothills, separated by broad and continuous longitudinal valleys" which grow wider toward the coast.[1] The even skyline which one might expect to result from the uplift and dissection of a peneplain is not everywhere apparent, because of subsequent volcanic flows of uneven thickness; although viewed over broad areas there is a certain evenness of summits which is apparent in spite of the flows, which were not of the cone-building type, but more like those which resulted in the formation of our Columbia Plateau.

An east-west profile of the Sierra Madre in southern Chihuahua and Sonora shows an average elevation of about 7,000 feet on the east, rising to 10,500 feet at the Continental Divide, and dropping again to about 6,800 feet at the western scarp.[2] The term "Continental Divide" should not be understood too literally, for it is not

[1] J. G. Aguilera, *Inst. Geol. Mex.*, V. [2] Weed, *op. cit.*

between the Atlantic and Pacific, but between the Pacific and the interior basins of the Anahuac Desert province.[1] There is also a drop in elevation of a few thousand feet from south to north in conformity with the slope of the tilted plateau block which constitutes the Mexican country.

The Sierra Madre Occidental is generally regarded as a mountainous country, and experienced geographers write of its "ridges," but it is important to note that the roughness of its topography is due to down-cutting rather than upheaval or upbuilding; in other words, the slopes of the region are to be regarded as canyon walls rather than mountain flanks.

This province has no important drainage to the east save by the Rio Conchos and the Rio San Juan, both tributary to other streams. All of the other streams which rise in the mountains and flow eastward are of the "suicidal" or "lost"[2] type and disappear soon after reaching the desert below, or flow into undrained lagunas (lakes), where their water is gradually evaporated. The profound work of dissection and denudation which one sees in progress east of the mountains is not due to these streams, but to other processes which will be described later.

On the west, normal processes of erosion are under way, and numerous subsequent streams are working headward and pushing back the western scarp of the plateau at a rapid rate. In many places these have captured the streams occupying the longitudinal structural valleys, the latter entering the former at angles varying from 45° to 90°.[3] Some of these western streams, particularly the Aros, the Fuerte, and the Rio Grande de Santiago, have incised their canyons a mile below the top of the plateau, and emphasize the fact that the rugged character of the country is not due to upward departures from the general level, but to profound down-cutting in the plateau. The greatest depression is in the Grand Canyon of the Bolanos, a tributary of the Santiago. The depth of this canyon is accentuated by the fact that it lies at the foot of the maximum crest of the mountains—the Sierra de la Yesca.[4] Experienced travelers testify that the scenery to be found in these canyons

[1] E. O. Hovey, *Bull. Phil. Geog. Soc.*, No. 4, p. 247.

[2] Hill, *Eng. and Min. Jour.*, LXXXIV, 633.

[3] Aguilera, *op. cit.*

[4] Ordonez, *op. cit.*

rivals that of our own Grand Canyon, which was produced by the same causes and at the same time.

It is along the courses of these westward-flowing streams that the dentate character of the sierras is seen to the best advantage. Their longitudinal tributaries separate chains or mountain masses, the western slopes of which are marked by precipitous fault scarps. The eastern slopes of these masses being more gentle, the profile is clearly imitative of the teeth of a saw.[1]

Many of the longitudinal stream valleys, before being tapped by the westward streams, were intermontane basins. On the sides of these valleys are now to be found undeformed, stratified beds, which were for a long time unaccounted for. They are now regarded as loosely cemented débris which had been carried down the slopes and deposited in the basins, which, when filled with water, formed lagunas, and constituted "settling tanks," as Hill has termed them,[2] where the detritus was roughly classified according to size and deposited in layers. They are of course of a past, but quite recent, geologic age.

The general structure of this province may be described as a series of folds, varying from a close, even recumbent, type, to broad swells, passing out northward into monoclines, over the erosion-beveled edges of which are spread flow upon flow of eruptive lavas. Le Conte, twenty years ago,[3] proposed the theory that these Sierras were formed by intense folding movements in Early Tertiary time, followed by profound drops at the sides of faults parallel to the folds; that along these lines of less resistance, successive and prolonged volcanic eruptions took place, and that subsequent active erosion accentuated the escarped form which affects most of the slopes. Later studies pursued by prominent Mexican geologists have confirmed this theory.[4]

In the canyon of the Aros there have been counted as many as nineteen separate lava flows, one above the other, with intervening beds of tuff and local conglomerate derived from the disintegration

[1] Ordonez, *op. cit.* [2] Hill, *Trans. A.I.M.E.*, XXXII, 163.

[3] Le Conte, "The Origin of Mountain Ranges," *Jour. Geol.*, September-October, 1893.

[4] Ordonez and Aguilera, *Inst. Geol. Mex.*, IV.

of the preceding flows. Erosion has affected unequally these tuffs and the harder lavas (rhyolites and dacites), and in consequence there have been produced, on many of the slopes, several terraces or "shoulders."[1]

Physiographic history.—The history of the present Sierra Madre Occidental begins properly with the uplift which brought the Cretaceous sediments out of the sea. This uplift continued to a considerable altitude and was accompanied by profound deformation, which took the form of close folds and overthrusts passing into faults, the strike of the entire system being approximately north-south. This uplift, which was an event of early Tertiary time, inaugurated the first erosion cycle, which, when completed, had removed some thousands of feet of rock and resulted in the formation of the "Cordilleran Peneplain."[2]

Following this peneplanation, toward the close of the Miocene,[3] another uplift occurred, accompanied by widespread vulcanism. Numerous vents were opened over the province, from which flowed an enormous quantity of slightly viscous lava. Uplift continued; in fact, is still in progress. In the meantime, a second erosion cycle began, during which there has been removed at least two thousand feet of volcanic rock, and which has seen the larger westward-flowing streams incise their canyons a mile below the top of the plateau.[4]

Recent work on the Grand Canyon of the Colorado has indicated a third erosion cycle, intermediate between the two just described.[5] It is impossible to determine from the data at hand whether it included the entire Mexican Plateau. It is certain that in some places the early eruptives (andesites) as well as the intrusives (diorites and granites) were deeply eroded before the later eruptives (rhyolites and dacites) appeared. However, the evidence of this third cycle is obscure, even where displayed to the best advantage, whereas the evidence of the two cycles described above is perfectly clear to experienced physiographers.

[1] Hovey, *Bull. Am. Geog. Soc.*, XXXVII, 531.

[2] Hill, *Eng. and Min. Jour.*, LXXXV, 681.

[3] Ordonez, *op. cit.*

[4] Hill, *Science*, N.S., XXV, 710.

[5] L. F. Noble, *Am. Jour. Science*, XXIX, 374–80.

At some date subsequent to the completion of the first cycle extensive orogenic movements changed the whole structural trend from north-south to about N. 45° W.[1] The profound faulting which accompanied these movements blocked out the entire country into its present shape, determined most of the prominent structural features, and opened avenues for the intrusion of vast igneous bodies which have been responsible for the primary mineralization of the province.

THE ANAHUAC DESERT PLATEAU

Definition and boundaries.—Many names have been applied to this portion of the old Mexican Plateau, such as the Mesa Central, Chihuahua Desert, and Anahuac Plateau. Hill has suggested the name Anahuac and it will be used in this paper, for it seems eminently appropriate to fasten upon this decayed remnant of a former widespread feature the name of the aboriginal race which inhabited it, and which centuries ago went into decadence along with it. The terms "desert" and "plateau" are included, for they are descriptive of the province. Furthermore, these terms serve to correlate this province with those of the United States which Fenneman has included under the name of desert plateaus.[2]

The Anahuac Desert Plateau is a degraded area of scattered block mountains and intervening "bolson" desert. It extends from the plains of Texas and New Mexico and Arizona on the north,[3] southward through the Mexican states of Chihuahua, Coahuila, Nuevo Leon, Tamaulipas, San Luis Potosi, Queretaro, and Hildalgo to the Valle de Mexico and the base of Xinantecatl (Nevado de Toluca).[4] The portion lying north of the International Boundary is well known under the names of Trans-Pecos Highlands and Arizona Highlands.

The northern boundary line runs eastward from the great bend of the Colorado River, along the edge of the Colorado Plateau, through Silver City, New Mexico, then turns northeastward and passes the southern ends of the San Juan and Sangre de Cristo mountains.

[1] Hill, *Science*, N.S., XXV, 710.
[2] Fenneman, *op. cit.*
[3] G. B. Richardson, *El Paso Folio, U.S. Geol. Survey.*
[4] Ordonez *et al.*, *Trans. A.I.M.E.*, XXXII, 259.

The eastern boundary follows the western slope of the Pecos valley to the southern edge of the Stockton Plateau.[1] Here it turns eastward along the Balcones scarp to the junction of the Pecos and Rio Grande. Here it turns again and continues in a southerly direction almost to Vera Cruz. In this part of its course it has been drawn on the 500-foot contour of the Bartholemew map, which is practically coincident with the western limit of sediments younger than Late Cretaceous as mapped by Willis. In the field, it should coincide with the line separating the undeformed sediments of the Gulf Coastal Plain from the folded rocks of the plateau.

The western boundary runs southward from the great bend of the Colorado River at the foot of the Grand Wash and Cottonwood Cliffs,[2] which represent the eastward-retreating scarp of the old plateau,[3] to the Gila River. From the Gila to Naco, Arizona, it follows the Rio San Pedro to the International Boundary. From this point southward the line has already been described in connection with the Sierra Madre Occidental province.

The southern boundary is drawn close to the edge of the volcanic area from Nevado de Toluca to Jalapa. It separates two easily distinguishable topographic divisions. North of it, denudation dominates the topography; south of it, great volcanic piles raise themselves above the general level. The Mexican National Railroad from Vera Cruz to Mexico City follows the same line for a considerable distance, and it is, I think, a safe assumption that the railroad survey took these topographic features into consideration.

Topography.—It is not possible to give a single descriptive statement of the topography of this province. Broadly speaking, it is a wide expanse of territory in which great islands of isolated mountain blocks rise above a vast sea of desert. This description may be applied with all faithfulness to the province through its entire north-south extent, but an important exception must be made with reference to the eastern and southern borders. In these places it is actually mountainous.

Beginning with the Sierra del Carmen and the Sierra del Burro, inconspicuous ranges of 5,000 feet altitude or less, just across the

[1] I. Bowman, *Forest Physiography*, Pl. I.

[2] *Ibid.* [3] Hill, *Eng. and Min. Jour.*, LXXII, 563.

Rio Grande from the Stockton Plateau, a chain rises above the desert level and increases gradually in height southward until it forms the Sierra Madre Oriental. These mountains increase in height southward until they attain truly magnificent proportions, with peaks reaching 10,000 feet or more in Hidalgo and Queretaro, where they meet eastward-extending spurs of the Sierra Madre Occidental and merge with them. The Gulf slope of these mountains is in many places a scarp dividing the plateau from the Gulf Plain. It is probable that this scarp marks the position of a great fault line having at some points a vertical displacement of at least 4,200 feet.[1] These mountains are not a continuous north-south barrier, like the western sierra, and the ramifications of the desert "extend through the passes of the limiting chains in many places and establish easy communication with the coastal lowlands."[2]

Travelers across the Trans-Pecos region of Texas and New Mexico are more or less familiar with the topographic forms which will be described as characteristic of the greater part of this province. Prominent among these are the north-south trending ridges, separated by broad plains—in part constructional and in part plains of degradation—many of the latter being of the basin type called "bolsons," from the Spanish word meaning "purse." A section across the Anahuac Desert Plateau in almost any latitude would show the same topographic features—"numerous isolated mountain ranges with intervening pocket valleys or wide expanse of undulating plain."[3] The general desert level has an altitude of from 2,000 to 4,000 feet, while the mountains generally rise above 5,000 feet, with an occasional peak ascending to 8,000 feet or more.

Other prominent features of the topography are the "lost" mountains, lagunas, medanos, and a peculiar formation known as "La Brisca."

Lost mountains are isolated mountain blocks standing in the desert, and so far removed from the main mass of mountains as to have no apparent connection with them. They are simply outliers (monadnocks) which have resisted denudation more effectively than the surrounding territory.

[1] F. L. Nason, *Econ. Geol.*, IV, 421.

[2] Aguilera, *Inst. Geol. Mex.*, VI. [3] Hill, *Eng. and Min. Jour.*, LXXXV, 681.

Lagunas are shallow ephemeral lakes, mostly found in the lowest parts of the bolsons, and fed by streams whose sources are in the neighboring mountains and which flow only during time of storm—the "suicidal" streams previously discussed.

Medanos are sand hills or dunes, similar to those of our lake shores or the Great Basin. They consist of finely disintegrated particles, derived from the weathering of the plateau, which are constantly moved about, frequently in a general northeast direction, by the high winds.

In our discussion of the Sierra Madre Occidental province we mentioned a peculiar, stratified deposit of a past but recent geologic age which had been formed in intermontane basins. It must be remembered that the Anahuac Desert Plateau province formerly presented the same topography as is found in the Sierra Madre Occidental province at the present time, the latter by its definition being a survival of former widespread conditions. The dissection and weathering of the type of deposit mentioned results in a characteristic feature known in Mexico as "La Brisca." It is a superficial volcanic agglomerate consisting of rhyolitic tuff carrying subangular fragments of other igneous rocks and which weathers into striking forms due to inequalities of hardness—pinnacled cliffs, domes, pillars, etc.[1]

The Rio Panuco and the Rio Conchos, a tributary of the Rio Grande, drain the greater part of the province, although a considerable area known as the Bolson de Mapimi in Chihuahua and Coahuila is without exterior drainage. This great bolson is not a single basin, for within it are to be found mountains of considerable elevation; but its elevations and depressions are so disposed that none of the water falling in it (which is a negligible quantity) reaches the sea.[2]

The Rio Grande is an interesting river from a physiographic viewpoint. At one time it emptied its waters into a great laguna that lay southwest of the present site of El Paso. It appears then that a headward-working tributary of a stream which probably had the course of the present Pecos-Rio Grande tapped this

[1] Hovey, *Bull. Am. Geog. Soc.*, XXXVII, 539.

[2] Bose, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 19.

laguna and diverted its waters to the Gulf of Mexico. But the channel of the stream was far to the south and west of the present course of the Rio Grande, to which it was gradually crowded by encroaching volcanic flows.[1] It has never recovered itself, and in the vicinity of El Paso wanders about with an abandon that perplexes those who are charged with the duty of maintaining a definite line for the International Boundary.[2]

The desert plains of this province are of two types—degraded and constructional. The former are the result of denudation of greater plateau heights; the latter represent valleys or basins filled by detritus derived from the degradation of neighboring areas.

The mountains show several types of structure, though generally they are tilted fault blocks. Mountains in which an igneous core has been thrust up through the sedimentaries are not uncommon. Many are of the "mesa" type, the volcanic capping protecting the soft limestones beneath from erosion. A typical "lost" mountain is to be found in the Santa Eulalia, situated a few miles southeast of Chihuahua City. It is a mass of folded Comanchean limestone mantled by superficial eruptive material, tuffs, and cinders, and at present rises about 1,500 feet above the desert level. Scattered over the surrounding desert lie piles of débris derived from the denudation of the original mountain, which stood several thousand feet above its present height.

Physiographic history.—The history of this province coincides with that of the Sierra Madre Occidental until the beginning of the second erosion cycle. In brief, its known history begins with the withdrawal of the waters of the Gulf of Mexico and the emergence of the land mass at the end of the Cretaceous period. Then followed deformation along general north-south lines, with accompanying or subsequent elevation to a height sufficient to be susceptible of active erosion. This elevation, which probably occurred during the early Eocene,[3] ushered in the first erosion cycle, which ended with the base-leveling of the country to the condition of the Cordilleran Peneplain.

[1] Richardson, *El Paso Folio, U.S. Geol. Survey.*

[2] Mrs. A. S. Burleson, *Natl. Geog. Mag.*, XXIV, 381.

[3] Ordonez and Aguilera, *Inst. Geol. Mex.*, IV.

A little speculative interest is attached to the making of this first peneplain. In humid regions the processes of erosion tend ultimately to reduce the land surface to a base-level which is at or near sea-level; but in an arid region of basin-drainage type erosion cuts down hills and aggrades the basins, so that the plane of reference to which both hills and basins will be brought ultimately is not sea-level, but some higher indeterminate level.[1] Now if aridity characterized this early Tertiary base-leveling period in Mexico (a condition of which we are not certain), it is possible that the peneplain resulting from the erosion of the first cycle was not made at sea-level.

Following this peneplanation another uplift took place; in fact, is still in progress. This was accompanied in the beginning, probably Miocene time,[2] by orogenic movements which altered the entire structural trend to a general northwest-southeast direction.[3] There also occurred at this time widespread volcanic activity, both extrusive and intrusive.

In the second erosion cycle inaugurated by this uplift there were probably a number of stages, for there exist in many places old erosion surfaces made on both sedimentaries and volcanics, covered and filled by later volcanic flows. At the end of the volcanic period erosion became the dominant factor in determining the topography, and has remained so until the present time; and it is this epoch in the history of the province that holds the greatest interest from a physiographic viewpoint.

All of the features of the topography of this province which we have previously discussed are due to erosion agencies peculiar to an excessively arid region. In humid climates water in some form is the chief agent of erosion, but in this province nothing is more scarce than water, and the excessive denudation which has taken place must therefore be attributed to other agents. Chief among these is a large diurnal temperature variation. A midday temperature of 130° F. is not uncommon over a large part of the province, and a midnight temperature of 50° F. is usual throughout most of the year in the same places. This gives a maximum daily variation

[1] W. M. Davis, *Jour. Geol.*, XIII, 381.

[2] Ordonez, *op. cit.*

[3] Hill, *Science*, N.S., XXV, 710.

of 80° F., and it is safe to assume that the mean daily variation is not less than 50° F.

These sudden and excessive changes in temperature produce expansion and contraction stresses which even the hardest rocks are unable to withstand, and consequently they crack, splinter, and chip off. Then by gravity these particles are dragged down the slopes, comminuting each other as they go, until when they reach a certain minuteness of size they are seized by the strong, ever-blowing desert wind, which, like a great winnowing machine, fans them away. Much of this rock dust is carried out to sea, some of it perhaps is carried hundreds of miles to the northeast to add to the accumulation of loess on our Great Plains. Sheet floods following storms play an important part in erosion, but they are quite subordinate to the process just described. In the words of Hill, "the Mexican Plateau is being literally blown away."[1]

THE SONORAN DESERT PROVINCE

Definition and boundaries.—This province is the most degraded portion of the old Mexican Plateau. It is 1,700 miles long and lies between the Sierra Madre Occidental on the east and the Pacific Ocean on the west. It includes parts of Nevada, California, and Arizona in the United States, and the Mexican states of Baja California, Sonora, Sinaloa, and Tepic.

The northern boundary line runs from the edge of the Colorado Plateau near the great bend of the Colorado River westward to the southern terminus of the Sierra Nevada Mountains. It has been drawn to agree with the line marking the southern edge of the Great Basin as described by Fenneman[2] and Bowman[3] and requires no further justification.

The western boundary extends southward from the southern terminus of the Sierra Nevadas, between the Tehachapi Mountains of the Coast Ranges and a group of mountains which Ransome has referred to as the Sierra de Los Angeles, and reaches the coast between Los Angeles and San Diego.[4] From this point southward it coincides with the Pacific coast line to Cape San Lucas, and then

[1] Hill, *Science*, N.S., XXV, 710.

[2] *Op. cit.* [3] *Op. cit.* [4] J. S. Diller, *Science*, N.S., XLI, 1045.

cuts across the mouth of the Gulf of California to Cape Corrientes, where it closes with the southern boundary.[1]

The eastern boundary has been described in connection with the Sierra Madre Occidental and Anahuac Desert Plateau provinces.

The southern boundary is really a prolongation of the eastern boundary, which makes a turn to the southwest from the valley of the Rio Grande de Santiago to Cape Corrientes.

Topography.—Although there is a certain homogeneity of topography which distinguishes this province from its neighbors, there is, nevertheless, a minor diversity of features within its boundaries. The features which force themselves upon the attention of the student of physiography are as follows: (1) a great structural trough, occupied by the Gulf of California, the Salton Sink, and the Coachilla and Imperial valleys;[2] this trough, if not an actual southern extension of the same, is at least analogous to the great downwarp of the Pacific coast which is occupied in succession northward by the San Joaquin, Sacramento, and Willamette valleys and the Puget Sound basin; (2) a destructional coastal plain of varying width bordering the open ocean and the Gulf of California; (3) a foothill region bordering the western foot of the Sierra Madre Occidental and the Arizona Highlands, of which the mountains of the Peninsula of Lower California are a counterpart.[3]

The bottom of the structural trough is below sea-level from Riverside County, California, to Cape Corrientes, with the exception of the delta of the Colorado River, which lies slightly above sea-level and separates the submerged portion, known as the Gulf of California, from the Salton Sink and the Coachilla and Imperial valleys, which are at present land surfaces, though one point is 275 feet below sea-level.

The coastal plain is very narrow where it borders the open ocean and on the east side of the peninsula. On the mainland it assumes a wedge shape, and varies in width from zero in Tepic to 70 miles in the northern part of the province. It is nearly level, with few elevations above 200 feet, and "plainly the bottom of the Gulf of

[1] Ordonez and Aguilera, *Inst. Geol. Mex.*, IV and VI.

[2] Bowman, *op. cit.*, p. 235.

[3] C. Botsford, *Eng. and Min. Jour.*, LXXXIX, 223.

California until recently."[1] The fact that it has but recently emerged does not make it a constructional plain, for only a superficial bed of sediments covers the surface, denuded before the last submergence. Northward into Sonora, Arizona, and California this subdivision of the province grades quite imperceptibly into the lowlands of the Colorado Desert, where it loses its featureless coastal plain identity and is characterized by old valley floors with intermittent streams, old valleys filled with alluvium, and isolated mountains half-buried under alluvium, plains eroded by sheet floods descending from adjacent mountains, and true desert areas, of which the Mojave Desert is typical.[2]

The foothill region represents a less advanced stage of erosion of the edge of the old plateau. It is also wedge-shaped, its width varying from 20 miles in the south to 100 miles in the north. Its average altitude is less than 2,000 feet, though here and there peaks rise to 5,000 feet or more.[3] These are outliers, representing the former extent of the plateau, and are genetically analogous to the lost mountains of the Anahuac Desert Plateau province, previously discussed.

Northward these foothills grade into mountains of a somewhat different kind—the Basin Range or fault-block type. They still may be regarded as remnants derived from the old plateau but which have suffered recent faulting, as well as the erosion of two cycles.[4] The mountains of the peninsula are counterparts of the foothills of the mainland. According to Botsford the correlation of the two is perfect, as indicated by the "extent and characteristics of the Miocene rhyolytes and dacites on both sides of the gulf."[5] Northward it is probable that these peninsular mountains grade into the type of which the San Bernardino Mountains are characteristic, and not into the Coast Ranges, as they are generally mapped.[6]

The average altitude of these peninsular mountains is higher than the mainland foothills, on account of less active erosion due

[1] C. Botsford, *Eng. and Min. Jour.*, LXXXIX, 223.

[2] Bowman, *loc. cit.*, p. 237.

[3] Botsford, *loc. cit.*

[4] Bowman, *op. cit.*, p. 236.

[5] Botsford, *loc. cit.*

[6] Diller, *loc. cit.*, and Ordonez and Aguilera, *op. cit.*, p. 52.

to an almost entire absence of rainfall, and in places peaks rise almost to the level of the original peneplained surface of the old plateau; for instance, Santa Catalina 10,135 feet and Mount San Bernardino 10,630 feet.

In the northern part of the province there are numerous features that have many of the earmarks of glaciation—cirques, moraines, kettle holes, etc.[1] In the San Bernardino Mountains there is scarcely any doubt that these features are of glacial origin, the evidence presented by physical characteristics being supported by a boreal flora and fauna in the higher parts of the range; in Arizona and Sonora, however, there is some question concerning their glacial origin, and able geologists have held different opinions on this point. One holds that they are due exclusively to ice action;[2] another attributes them to volcanic brecciation and subsequent sheet flood erosion.[3] Inasmuch as either process would produce subangular fragments of varying size and would transport them to considerable distances from their point of origin, it is difficult to decide which is the more probable theory. Recent field work has not contributed much to the discussion.

The prominent drainage feature of this province is the Rio Colorado. It is of interest to physiographers for several reasons. Although it flows hundreds of miles through an arid country, without tributaries, and loses much of its original volume by evaporation, it delivers at its mouth a great volume of water, particularly from April to June. In this water is a larger average amount of suspended matter per unit volume than in that of any other North American stream, about twenty thousand parts per million, or enough to cover one hundred square miles of territory to a depth of one foot in a year. This accounts for its rapidly growing delta, and the cutting off of the Salton Sink and the Imperial and Coachilla valleys area.[4]

The lower course of this stream was consequent upon the surface of the great downwarp between the peninsula and the mainland.[5] In the bed which it found in this trough the river cut a canyon,

[1] Merrill, *Science*, N.S., XXIV, 117.

[2] *Ibid.*

[3] W J McGee, *Science*, N.S., XXIV, 178.

[4] Bowman, *op. cit.*, pp. 238–40.

[5] Botsford, *loc. cit.*

the mouth of which was on the coast somewhere between Cape San Lucas and Cape Corrientes.[1] This cutting may have been coincident with the elevation succeeding the downwarping or it may have occurred at some indefinitely later time. It is certain, however, that the depth of the gulf is not due alone to drowning by the sea, but largely to stream-bed corrasion incident to elevation. The maximum corrasion is estimated by Botsford to have been at least 6,000 feet.[2]

On the peninsula, but four small streams cut the coast line of more than two thousand miles. This is due to the fact that there is little or no precipitation. There are extensive areas on the peninsula where not a drop of rain has fallen in many years, which are characteristically desert in aspect and condition, even to the extent of supporting a fauna which apparently does not require water. In striking contrast to these conditions is the Sierra Pedro Martir, located in the northern part of the peninsula. This is a high plateau remnant, forested with conifers, and threaded here and there by small watercourses which flow through grassy and even marshy meadows.[3] Here cactus and yucca give way to conifers; and the horned toad and desert fox are replaced by mountain sheep and deer. In short, the region is the habitat of a fauna and flora akin to that found in the western mountains of the United States.

The reason for this change from desert conditions which exist on all sides is to be found in the height of the area, which causes it to receive considerable snowfall from December to April. The water from the melting snow lies close to the surface of the undrained plateau during a large part of the remainder of the year and gradually finds its way to springs scattered at lower altitudes. This condition dies out gradually down the gentle slope to the Pacific but ends abruptly at the scarp overlooking the gulf.

On the mainland, east of the gulf, there are numerous short streams which have their sources high up in the Sierra Madre Occidental, and receive considerable water during the rainy season. Many of these are dry during the greater part of the year, but are,

[1] Ordonez and Aguilera, *op. cit.*, p. 52.

[2] Botsford, *loc. cit.* [3] North, *Am. Geog. Soc. Bull.*, XXXIX, 544.

nevertheless, active agents of erosion when carrying the excessive run-off which follows precipitation on the bare desert slopes. The Sonora, Yaqui, Fuerte, and Rio Grande de Santiago rise farther back in the mountains and have a continuous flow. The canyons which these latter streams have cut through the mountains and foothills are of profound depth, and present to the traveler a sublimely rugged scenery, not to be surpassed on the continent.

The structure of this province is quite complex on account of the extensive folding, faulting, and vulcanism to which it has been subjected. A cross-section would show folded sedimentaries, upon the beveled edges of which sheets of volcanic material are spread, and into which dikes, plugs, sills, laccoliths, and other igneous bodies have been intruded. The whole mass is broken by numerous faults, chiefly of the N. 45° W. system, though east-west faults are common and occasionally profound, one in the Cananea district having a vertical displacement of at least 1,000 feet.[1] The topographic effect of the predominating N. 45° W. faults is to be seen in the scarps of the western border of the Sierra Madre Occidental and of the eastern border of the peninsular mountains.

Physiographic history.—When this province emerged from the sea after receiving its thick deposit of Mesozoic sediments it was subjected to stresses, which resulted in close folding and in the making of the great synclinal trough previously described. Following this, in early Tertiary time, there came a period of erosion which beveled the edges of the folded strata and resulted in the making of the "Cordilleran Peneplain," previously described.

After the country had been base-leveled, vulcanism began to play an important rôle, and during the Miocene great masses of volcanic material were poured out from numerous vents, completely burying the sedimentaries. Coincident with this a second uplift occurred, giving the streams renewed energy and causing erosion to become the dominant process in the making of the topography. It was during this second uplift, which probably is still in progress, that the Colorado River cut its trench several thousand feet deep through the Pacific trough.[2] The remainder of the province was not seriously affected in the beginning by the erosion of this period,

[1] M. L. Lee, *Econ. Geol.*, VII, 324.

[2] Botsford, *op. cit.*

because of its thick volcanic cap. During the early stages of this second cycle the synclinal trough was depressed, allowing the sea to encroach as far north as the Salton Sink, about 200 miles farther northwest than at present. At that time, "the mouth of the Colorado River was at Yuma, sixty miles from its present location, and was gradually building a delta that extended southwest toward the Cocopa Mountains. Deposition continued until the upbuilding of the delta had completely separated the head from the rest of the gulf, and converted the floor of the former into an inland sea."[1] At numerous times since, the Colorado has alternately emptied into the Gulf and into the lake or inland sea which it created.

The greater part of the degradation of the province has occurred during recent epochs of the period of second uplift. When once the volcanic capping is worn through, the softer sediments beneath erode with remarkable rapidity, and the larger westward-flowing streams have cut canyons of abysmal depths in them, in their short but steep courses to the sea. The smaller intermittent streams working headward into the plateau are attacking the softer rocks wherever exposed, and, with the sheet floods which follow the torrential downpours characteristic of the province, are doing a work the results of which are not so likely to attract attention as canyon-cutting, but which are infinitely more profound in the degradation of the plateau.

THE GULF COASTAL PLAIN PROVINCE

Definition and boundaries.—This province is a plain composed of recent and undeformed marine sediments. Being a southern extension of a similar feature in the United States it has no proper northern boundary, but is continuous through the Gulf states and up the Atlantic as far as Long Island.

Its western boundary has been described in connection with the Anahuac Desert Plateau province.

The eastern boundary, in common with that of the remainder of the coastal plain in the United States, may be taken as the border of the continental shelf, and is, of course, many miles east of the present coast line, which is but an incidental feature.

[1] Bowman, *op. cit.*, p. 239.

Inasmuch as both eastern and western boundaries of this province might be extended into Central America, it has no southern boundary as far as Mexico is concerned.

It is evident that the coastal plain is divisible into two parts, one submerged and the other a land surface. Of the former there is little to be said, save that its depth below sea-level is in most places very slight; the charts of the United States Coast and Geodetic Survey show but 30 fathoms at a distance of 125 miles out from the mouth of the Rio Grande.

The landward portion has its greatest width along the International Boundary, where it attains a width of about 225 miles. South of Brownsville the province narrows suddenly and continues to grow narrower until at Tampico it has practically no development at all. This condition continues with more or less variation as far as Vera Cruz. South of this point there is a gradual widening which increases with distance until, in the peninsula of Yucatan, the plain has a maximum width of over 300 miles.

Topography.—The most prominent topographic features of this province lie close to the coast line—a multitude of spits, bars, coastal islands, lagoons, and salt marshes. The greater part of the surface above tide is a featureless flat, which terminates rather abruptly at the foothills of the Sierra Madre Oriental.[1] It is not possible to draw a straight line of any considerable length between the coastal-plain type of topography and that of the mountains. Indeed, it is common to find jutting headlands of the Sierras and reduced areas of intrusive rocks almost down to the water's edge,[1] and on the other hand to find recent marine sediments in the coves 40 or 50 miles inland. This condition has already been explained and is mentioned again only to justify the generalization of the boundary line.

No large or important streams cross the province south of the Rio Grande. The paucity of streams and the number of lakes are noteworthy features of the peninsula of Yucatan. This condition is closely related to the lithology of the bedrock. This consists of thick beds of limestone and shale of Cretaceous age. Where the coastal plain is narrow, as in the vicinity of Tampico, these deposits

[1] V. R. Garfias, *Jour. Geol.*, XX, 666.

are deeply covered by marine sands supplied by the débris washed down from the eastern edge of the plateau, but on the peninsula, where the plain is very wide and the greater part of it at a considerable distance from the mountains, the limestones are close to the surface. These limestones are of a particularly soluble character, and on account of the low, flat, or undulating surface, the heavy rains of the region soak into the ground and percolate through them, developing great caverns (*cenotes*). Where the cavern roofs have fallen in the natural channels of circulation are stopped, and water fills the depression, forming shallow ponds (*akalches*).[1] In other places the waters continue to circulate downward until they strike a stratum of impervious shale, along which they move in underground channels to the sea, or upon which they form subterranean lakes. These form the only permanent natural sources of water on the peninsula, and as a result they are of considerable economic value.

Physiographic history.—As in other sections of the Atlantic Coastal Plain, the later history of this province may be summed up as a series of submergences and emergences. At times, perhaps several times, the present land portion has been under water. At other times the present submerged portion has been above the sea, even to the edge of the continental shelf. The tendency at this time is toward a submergence of the present land surface portion.[2]

THE VOLCANIC PROVINCE

Definition and boundaries.—This province embraces a high mountainous strip of country in which the axes of folding are aligned east-west, and in which the departures from the general level are upward instead of downward, as elsewhere over the plateau. The province extends across Mexico in an east-west direction from Cape Corrientes to Jalapa. Early geographers called it the "Cordillera de Anahuac,"[3] but the term has fallen into disuse because it is now recognized that it is as much an integral part of the great Mexican Plateau as the Sierra Madre Occidental.[4]

[1] Huntington, *Bull. Am. Geog. Soc.*, XLIV, 801; V. R. Garfias, *Inst. Geol. Mex.*, III, 18.

[2] C. Sapper, *Inst. Geol. Mex.*, III.

[3] Virlet de Aoust, *Bull. Soc. Geol. de France*, 2d Ser. XXIII, 14–15, 1866.

[4] Aguilera, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 7, p. 3.

The northern, western, and eastern boundaries have already been described in connection with other provinces. The southern boundary line extends in a general way from Cape Corrientes along the courses of the Rio Armeria, the Rio Tepalcatepec, the Rio Balsas, the Rio Mexicala, and the Rio Atoyac, all of which skirt the southern edge of the recent volcanic flows, to the vicinity of Esperanza, and then around the volcano of Orizaba and the Cofre de Perote to Jalapa. The change in topography when one crosses the boundaries of this province are sharp and definite, and if not always comprehended in a single view, at least become apparent within a few miles.

Topography.—Viewed from any commanding eminence, this province presents a wildly rugged topography—"a variegated sea of rolling, timber-covered, constructional, volcanic hills, mesas, peaks, and monticules, alternating with basin valleys and plains."[1] The great altitude of the major portion of the province (8,000 feet and upward) is not due alone to the higher altitude of the plateau itself, although it is 5,000 feet above El Paso, but to the vast quantities of volcanic material which have been ejected from numerous vents and piled upon it.

This volcanic material consists not only of lava, but also of tuffs and pumice, in some places *in situ* and in others as old lacustrine deposits. The material from which these lacustrine deposits were made was derived by erosion from the surrounding volcanic heights and carried into the lakes, raising their waters until they overflowed into neighboring streams, and finally filling the lakes completely. As many of these Pliocene and Pleistocene lake beds were of considerable areal extent, their deposits have effaced much of the pre-existing volcanic topography.[2]

It is probable that the plain upon which the higher peaks rest was formed simultaneously with them. According to Ordonez the more fluid portions of the magma were ejected from the vents by violent explosions and raised into such prominent andesitic cones as Popocatapetl and Ixtaccihuatl, while the denser basalts flowed from connecting fissures to form the "badland" plains surrounding them.[3]

[1] Hill, *Eng. and Min. Jour.*, LXXIX, 410.

[2] Ordonez, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 8 and plate.

[3] Ordonez, *ibid.*, No. 1, p. 4.

Figures are totally inadequate to express the amount of this extrusive material. Even using the largest familiar units of volume they would run into orders which no mind is capable of comprehending. There are a half-dozen or more peaks rising from 5,000 to 10,000 feet above the plateau, and these are but stubs of former peaks which have been reduced by erosion.[1] A few of these are worthy of particular mention.

Orizaba, the "shining star" or "Citlaltepetl" of the Aztecs, is a majestic cone which rises from the eastern edge of the plateau to a height of 18,240 feet above the sea, and is visible 80 miles out from the coast.[2] Popocatepetl, the "smoking mountain," is built upon the plateau just south of Mexico City. It rises 17,520 feet above the sea and has a crater half a mile in depth and of the same diameter, from which steam and sulphur gases escape continually, proclaiming it not extinct, but dormant. Ixtaccihuatl, "the woman in white," raises its cone just east of Popocatepetl and to a height of 15,082 feet; and Toluca, called in the Aztec tongue Xinantecatl, and supposed to mean the "nude man," is situated just west of Popocatepetl and rises to a height of 13,000 feet.[3] The Cofre de Perote, or "Nahucampatepetl," to the north of Orizaba, rises to a height of 13,411 feet. Volcano Jorullo in Michoacan belongs to the third era of eruption, which will be discussed under the head of physiographic history, and although not situated on the plateau is a sort of "outlier" of this province. It rises from an amphitheater almost 3,000 feet below the level of the plateau.[4] Colima, on the western edge of the plateau, shows an altitude of 12,664 feet, while numerous other cones, somewhat lower, though scarcely less imposing, dot the plateau in many places. Most of the cones are of the "strato-volcanic" type and show plainly the several flows of which they were built.[5]

The volcanoes of Colima, Popocatapetl, and Orizaba are unique in that they consist of twin peaks, one with a crater and the other

[1] Hill, *Eng. and Min. Jour.*, LXXXV, 681–88.

[2] Melgareo, *Natl. Geog. Mag.*, XXI, 741. [3] Melgareo, *loc. cit.*

[4] Ordonez, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 9.

[5] Hovey, *Science*, N.S., XXV, 764; T. Flores, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 9, p. 14.

without. The names used herewith are applied to the peaks with craters. Their accompanying craterless cones are known respectively as Nevado, Ixtaccihuatl, and Cofre de Perote. From a distance, Nevado appears to have a crater, but this is in reality but a furrow, produced jointly by the sinking of the lava crust and later erosion. The few geologists that have studied the phenomena have apparently avoided giving an explanation of the genesis of the craterless peak, and the single reference available does no more than cite the analogy between these and a type described by Stübel in Ecuador.[1]

Numerous basins, formed in constructional depressions in the volcanic surface, are scattered over the province. These abound in the environs of the city of Mexico. The city itself is situated in the so-called Valle de Mexico, which is an inclosed basin 50 miles long by 35 miles wide. This basin contains six shallow lakes and a considerable area of marshes. This marsh area is all the more unique and interesting when it is considered that it lies at an altitude a mile and a half above sea-level. The drainage of this basin, which is of the first order of necessity for sanitary living during the rainy season, was an engineering problem which defied successful solution for three centuries. Finally, in 1900, there was consummated a successful plan involving a seven-mile tunnel under the Xalpam Mountain, and an aqueduct over the Guadalupe River, by which the sewage and storm water of the city of Mexico is drained from the basin and emptied into a stream which carries it to the Gulf of Mexico.[2] Many of the basins are filled with water, forming lakes of considerable size, namely, Chapala, Quitzeo, and Patzcuaro, all in the state of Michoacan.

Among other interesting topographic features are the cinder cones and their crater lakes of the Valle de Santiago, and the pit craters of the state of Pueblo. The former are low cones of ash and breccia, eleven in number, the craters of which vary in diameter from 1,500 feet to one mile. The bottoms of some of these craters contain shallow lakes of clear, fresh water (*xalalpascos*). This

[1] P. Waitz, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 13, pp. 10–21.

[2] S. F. Emmons, *Science*, N.S., XVII, 309.

water is not derived directly from rainfall, but from a subterranean sheet flowing under the porous volcanic soil. The slopes of the craters, both interior and exterior, are frequently covered with green, cultivated fields.[1] These craters are generally regarded as having been produced by explosions caused by steam generated when superficial water came in contact with heated rocks below.[2] The basis of this opinion is the fact that the stratified basaltic flows and beds of tuff forming the plain in which these craters are discovered have not been disturbed profoundly, the eruptions appearing to have been strictly local.[3]

The pit craters of Pueblo are apparently similar features. These occupy the centers of cones which rise with very gentle slopes to slight elevations. They are from 3,000 feet to a mile in diameter, and average 150 feet in depth. On the floors of the craters are lakes of fresh water, and their walls show plainly the stratified volcanic beds of which the plain on which they stand is composed. In places are to be observed breccia-filled stream channels, buried under the eruptives which built the cones and formed the craters.[4] Their genesis is no doubt similar to that of the cinder cones described above, though no less an able geologist than Ordonez states that they seem unduly large for the explosive force which is generally regarded as having produced them.[5] Both types of phenomena are relatively recent features of the topography, and probably belong to the second period of vulcanism, to be discussed later.

The important drainage systems of this province are those of the Rio Grande de Santiago, the Rio Lerma, and the Rio Balsas of the Pacific slope, and the Rio Papaloapam with its tributaries and a few small streams of the Atlantic slope. The Rio Lerma is really the upper course of the Rio Grande de Santiago, which is divided about midway in its course by Lake Chapala. The two streams and the lake together form a watercourse about 800 miles in length, the largest in Mexico, if we omit the Rio Grande del Norte, having a drainage basin of about 60,000 square miles. In

[1] Ordonez, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 14.

[2] Hovey, *Bull. Am. Geog. Soc.*, XXXVIII, 730.

[3] Ordonez, *loc. cit.* [4] W. M. Davis, *Science*, N.S., XXVI, 226.

[5] Ordonez, *Inst. Geol., Mex., Los Xalalpasgos del Estado de Pueblo.*

places its gradient is very steep. Near Guadalajara there is a beautiful falls with a sheer drop of 100 feet, and above La Juntas the stream descends 1,800 feet, over a series of cascades, in a distance of 15 miles.[1]

The structure of this province is difficult to determine, owing to the concealment of all early formations by the more recent extrusives. Where it has been possible to obtain data, however, it has been interpreted as follows: bedrock of massive Cretaceous limestones and shales, folded along east-west axes, badly faulted, cut by granitic intrusives, and covered by a great cap of lava and tuff.

This is the first province to be discussed where the structural trend is east-west. Ordonez thinks that the number and disposition of the volcanic craters along the Rio Grande de Santiago suggests the idea of its marking the line of an important fracture, corresponding to a place of dislocation in the general elevation of the plateau, and where it has brusquely interrupted its direction (northwest-southeast) and effected a movement in a different direction (east-west).

Physiographic history.—The early history of this province is similar to that of the rest of the plateau, as far, at least, as the making of the Cordilleran peneplain and the second uplift; beyond that it is obscure. We may infer, however, that the second erosion cycle had proceeded to the extent of cutting rather deep valleys in the sedimentaries before the first eruptions occurred. The first flows filled these valleys, leaving hills of sedimentaries standing out above them. Erosion continued, and in time these hills were reduced to valleys, and the lava-protected valleys became hills and mountains. Over the greater part of the province later vulcanism completely effaced all traces of these earlier events, and built the great volcanic plain and the peaks which now characterize the province, and it is only around its borders that this part of its history may be determined.[2]

It appears that there have been two periods of vulcanism in this province: the first in the Miocene and affecting all Mexico;

[1] H. A. Horsfall, *Eng. and Min. Jour.*, LXXXVIII, 665.

[2] Hill, *Eng. and Min. Jour.*, LXXIX, 410.

the second beginning in the Pliocene and continuing to the present time and limited to this province.[1] This second period appears to have been divided into three well-defined epochs: first, that which produced the high peaks and cones; secondly, that which produced the pit craters; thirdly, that which is manifested in the hot springs and geysers of the present time. Between the first and second epochs there was a time of lesser activity during which were produced the minor cones which have since been reduced to slight eminences.[2]

An exception is found in Colima, which according to the classifaction given would belong to the first epoch of the second period. This volcano has erupted at intervals during the life of the present generation. The eruptive material has not consisted of lava, but of glassy fragments of various sizes. It has been assumed that the eruptive forces at work during this latter epoch of activity have not been sufficient to overcome the altitude of more than 12,000 feet, and that therefore the lava rises to a much lower level in the crater and only the hot scoriae are ejected over the sides.[3]

As we have indicated, the second erosion cycle in this province was interrupted by widespread and long-continued vulcanism. Since the cessation of volcanic activity, erosion has again become the dominant factor in making the topography of the province. Shall we call this a continuation of the second cycle or the beginning of the third? Inasmuch as the topographic effects of the second erosion cycle were largely obliterated, and as early youth is manifested over a large part of the province, I believe we are justified in stating that a third cycle is beginning, and although it is by no means certain that the titanic forces which built up this area are exhausted, erosion seems to have the better of vulcanism in the contention for supremacy.[4]

THE SIERRA DEL SUR PROVINCE

Definition and boundaries.—This is the southernmost division of the old Mexican Plateau and is in all essential respects, save

[1] T. Flores, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 9.

[2] Ordonez and Aguilera, *op. cit.*, p. 80.

[3] J. M. Arreola, *Jour. Geol.*, XI, 749.

[4] Ordonez and Aguilera, *op. cit.*, p. 80.

the direction of its folds, a counterpart of the northern provinces, from which it has been cut off by the volcanic flows of the province, previously described. It would no doubt fall under the discussion of the Sierra Madre Occidental province were it possible to connect with that. The volcanic area, however, has completely isolated it, and it therefore requires separate treatment. It is an area of odd shape, aligned roughly with the folds, and lies between the volcanic area on the north and the Pacific Ocean on the south.

The northern boundary has been described, and for the greater part of its length is a natural dividing line separating two regions of widely different types of topography. The Pacific Ocean forms a natural southern and western limit and the remainder of the boundary line is drawn at the foot of the escarpment, where the edge of the plateau rises above the lowlands of the Isthmus of Tehuantepec. (Compare the accompanying sketch map, Fig. 1, with the Bartholomew topographic map previously referred to.)

Topography.—In the general literature of Mexican geology and geography this area is frequently described as though it were a part of the volcanic area. Such description is erroneous, however, for here again the characteristic feature of the topography is plateau dissection. It duplicates the erosional features of the northern provinces and is unaffected by the extrusions which characterize the Volcanic province.[1]

The interior is a labyrinth of mountain ranges trending in diverse directions, with here and there an occasional peak, more resistant than its neighbors or by its configuration less exposed to erosion agencies, rising to a height comparable to that of some of the volcanic cones.

On the Pacific side, head-working streams are rapidly degrading the plateau, leaving its front a tattered edge, with long headlands jutting out between the stream courses. The Rio Balsas, which in its upper course is known as the Rio Mexcala, is one of the most important streams in Southern Mexico, and drains a large portion of the interior of both this and the Volcanic province. The Rio Tehuantepec of the isthmian slope is remarkably straight in its lower course, and without tributaries there. In the upper course,

[1] William Niven, *Eng. and Min. Jour.*, XC, 672.

however, it is developing a typical dendritic system of drainage, and is rapidly dissecting the plateau in Oaxaca. The stream was probably originally consequent upon a fault rift in the steep slope of the plateau edge flanking the isthmus, but has since lengthened its course and developed a drainage basin by processes characteristic of subsequent streams.[1]

The structure on the whole is similar to that described for the northern provinces, namely, folded, faulted sedimentaries, overlain with superficial volcanic material, and intruded by various igneous bodies; but the trend of the folds here is generally east-west. Over the greater part of the province the Miocene volcanic cap has been removed, laying bare the metamorphosed sediments beneath. In addition to having the sedimentaries clearly exposed, we know the character of the actual basement rock—a condition which may only be surmised over the rest of Mexico. The basement rock in this province is Archean crystallines, which may be observed in the deepest canyons not far above sea-level and upward to positions on mountain flanks 6,000 feet above tide.

Physiographic history.—In the other Mexican provinces we were obliged to begin the history at the first post-Cretaceous cycle. Here, although we have Archean rocks determining the topography in places, history must again begin with the Mesozoic era, for the Paleozoic record is a blank. We have Mesozoic sediments resting unconformably on Archean crystallines. How many erosion cycles, or what length of time was necessary completely to remove all traces of Paleozoic rocks and carve deeply into the crystallines, is indeterminable. There is little evidence to warrant the belief that the Mexican Plateau was an island during the Paleozoic era, and consequently without marine sediments. Moreover, there are Paleozoic rocks exposed in small patches in Sonora, and again in Chiapas and Central America[2] and I believe we may safely infer that they once covered the entire plateau and were removed. After the uplift of the plateau following the deposition of the Mesozoic sediments, the history of this province becomes coincident with that of the northern provinces.

[1] Bose, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 31, p. 21.

[2] Hill, *Eng. and Min. Jour.*, LXXXIV, 63.

THE TEHUANTEPECAN PROVINCE

Definition and boundaries.—This province comprises an area of very old, low-lying rocks occupying the Isthmus of Tehuantepec. If we were to draw province boundaries on a basis of topography alone we should be obliged to include most of this area in the Gulf Coastal Plain province, for there is scarcely any difference in topography. But considering also structure and history, we are compelled to make this a separate province, with boundaries as indicated on the accompanying sketch.

It is bounded north and south respectively by the Gulf of Mexico and the Pacific Ocean. The greater part of the western boundary is the scarp of the plateau, which rises 8,000 feet above the isthmus,[1] while to the east the heights of Chiapas rise to an almost equal altitude.[2] Between these two highland areas lies the isthmus, like a great block dropped out of an arch.

Topography.—The isthmus is an area of low, rounded hills, with two regional slopes, the longer toward the north and the shorter toward the south, the two slopes meeting to form a divide at Tarifa Chivela. Both slopes are very gentle, and the maximum altitude at the divide is less than 800 feet.[3]

The drainage follows the regional slopes, regardless of structure, the Rio Coatzalcoalcos and its tributaries draining northward, and the Rio Geronimo, southward.

Physiographic history.—The oldest rocks exposed in this province are the Archean crystallines, in the vicinity of Tehuantepec. Farther up the slope at Chivela are metamorphosed sediments of probable Paleozoic age, and still higher, unaltered Middle Cretaceous and Upper Miocene. Down the Atlantic slope, Pliocene deposits grade into the Recent sediments of the coastal plain.

It may be a permissible figure to speak of the isthmus as a block dropped out of an arch, but as a matter of fact it will require us to postulate more profound changes than the mere dropping of a fault block to account for the peculiar structure of the isthmus.

[1] Hill, *Trans. A.I.M.E.*, XXXII, 163.

[2] Bose, *Guides des excursions, 10th Inter. Geol. Cong. Mex., 1906*, No. 31.

[3] Bose, *op. cit.*, profile sketch.

The low mountain chain running through Tarifa Chivela is probably a spur of the Mexican Mountains—a southward extension of the Sierra Madre Occidental perhaps—that came into existence with the Cretaceous-Eocene uplift; the plicated and metamorphosed sediments are to us as a mutilated page torn from an important but now missing chapter in our historical account of Mexican physiography; and the low swells and undulations of the Atlantic slope are the result of the uplift and deformation that "constructed the bridge between the two American continents."[1]

Summing these events up in chronological order we may say that upon the fundamental Archean complex were deposited a series of Paleozoic rocks of unknown thickness and areal extent. These were so profoundly deformed as to become highly metamorphosed. Following the deformation came a period of erosion which probably continued until the Middle Cretaceous submergence. In other words, the pre-Mesozoic history of this province probably was coincident with that of the Mexican Plateau, of which the isthmus was no doubt an integral part. At the time of the uplift referred to a great structural movement took place which cut this province off from the remainder of the plateau, the place of rupture being still visible in the great scarp in Oaxaca. The dropping of the block on the east of this fault line brought about the inundation of what is known as the isthmus. The character and distribution of the Tertiary deposits would indicate that the submergence thus produced was not to great depths. In late Tertiary and early Quaternary time an orogenic movement took place which produced a second series of folds, and raised the isthmus above the sea. This movement is to be regarded as an event peculiar to Central America, at all events to that part of the country south of Oaxaca. The Mexican Plateau was not affected.

[1] Bose, *op. cit.*, p. 26.

Reviews

The Mississippian Brachiopoda of the Mississippi Valley Basin. By STUART WELLER. Monograph I, State Geological Survey of Illinois, June 10, 1914. Pp. 508, pls. 83, figs. 36.

In the introduction a brief description and classification of the Mississippian formations as shown along the Mississippi River and in adjacent regions is given. The formations recognized and described are as follows:

V. Chester group.
  Clore formation.
  Palestine formation.
  Menard formation.
  Okaw formation.
  Ruma formation.
  Paint Creek formation.
  Yankeetown formation.
  Renault formation.
  Brewersville formation.
IV. Ste. Genevieve limestone.
III. Merrimac group.
  St. Louis limestone.
  Salem limestone.
II. Osage group.
  Warsaw formation.
  Keokuk limestone.
  Burlington limestone.
I. Kinderhook group.
  Containing many formations more or less local in their geographical distribution.

Weller has submitted these Mississippian brachiopods to a rigorous, critical study and revision. The method of study by working out the internal anatomy had already been outlined in his paper on the "Internal Characters of some Mississippian Rhynchonelliform Shells.[1]

Since the literature on these fossils has long been in an unsatisfactory and incomplete condition, the revision and redescription of the known forms with the added new species and genera will be welcomed by all students of the fossils of the Mississippian rocks.

[1] *Bull. Geol. Soc. Amer.*, XXI (1910), 497-516.

"The present work is a start toward the publication of a series of monographs which it is hoped may eventually cover all the groups of organisms whose fossil remains are preserved in these formations." The scope of the present work is practically that of the Mississippian rocks of Illinois, Missouri, and Iowa, the typical Mississippian section.

All the genera and all the species are described and abundantly illustrated. More than that, all the old descriptions of species have been rewritten, "so that the usage of terms is uniform throughout."

There are 62 genera and 297 species described. Of this number 4 genera and 80 species are new to science. The limits of the genera and species are closely drawn throughout. However, they are no more closely drawn than is necessary to give a clear understanding of the anatomical relationships and to give proper stratigraphic value to a species. This does not necessarily imply that all the genera are limited to a few species, since there are 44 species of the genus *Spirifer* recognized as valid and described from the Mississippian rocks of the Mississippi Valley basin. The list of species described as new is given herewith, together with the critical characters of the new genera: *Lingula louisianensis*, *Leptaena convexa*, *Schuchertella ferglenensis*, *Schellwienella crenulocostata*, *S. chouteauensis*, *S. planumbonum*, *S. alternata*, *S. burlingtonensis*, *Streptorhynchus tenuicostatum*, *Chonetes missouriensis*, *C. chesterensis*, *Productella sublaevis*, *Productus mesicostalis*, *P. crawfordsvillensis*.

The genus *Echinoconchus* was erected for those species of *Productus* with "more or less sharply differentiated concentric bands which commonly grow broader in passing from the beak to the outer margins, each band bearing numerous, crowded, fine, appressed imbricating spines, either subequal or unequal in size, which are produced from elongate, node-like bases." *Productus punctatus* is the genotype. It so happened that a work entitled *The British Carboniferous Producti*, the first part, by Ivor Thomas, was issued on June 6, four days prior to the issue of Weller's monograph. In this memoir,[1] treating of the first part of the genus, apparently the same group of shells are gathered under the genus *Pustula*. If they are the same, this term, having priority, will be used instead of Weller's term given above. The genus corresponds with Waagen's section IV, *Fimbriati*, in a general way, as published in the *Salt Range Fossils*, *Brachiopoda*, p. 671. The species referred by Weller to the genus are: *P. alternatus*, *P. genevievensis* n.sp., *P. biseriatus*, *P. morbilianus*.

[1] *Memoirs Geological Survey, London*, I, Parts 2, 4, June 6, 1914.

Continuing with the new species: *Rhipidomella jerseyensis, R. tenuicostata, Schizophoria chouteauensis, S. Sedaliensis, S. poststriatula, Camerotoechia subglobosa, Allorhynchus acutiplicatum, Rhychotreta elongatum, R. missouriensis, Tetracamera missouriensis, Rhynchophora? rowleyi, R.? perryensis, Centronella louisianensis.*

Under the Terebratulidae a new genus, *Centronelloidea*, is erected. "In its external form this genus is like *Centronella*, but its brachidium is essentially like *Dielasma*, although the development of the crutal lamellae in the rostral portion of the brachial valve is entirely different from that genus." *T. rowleyi* is the only known species.

Cranaena globosum, C. sulcata, Dielasma chouteauensis, D. osceolensis, D. sinuata, D. inflata, D. illinoisensis, D. arkansanum, D. subspatulatum, Girtyella cedarensis, G. intermedia, Dielasmella calhounensis, Atrypa infrequens, Spiriferina saleminsis, Delthyris similis, Spirifer shepardi, S. platynotus, S. biplicoides, S. legrandensis, S. crawfordsvillensis, S. washingtonensis, S. pellaensis, S. breckenridgensis, S. marshallensis, S. floydensis, S. indianensis, S. maplensis, S. subrotundatus n. nom., S. gregeri, S. rowleyi, S. montgomeryensis, S. calvini, Brachythyris burlingtonensis, B. gurleyi, B. altonensis, Cyrtina inexpectans, Syringothyris bushbergerensis, S. newarkensis, S. platypleurus, S. solodirostris.

The genus *Pseudosyrinx* is erected "to include a group of spiriferoid shells with high cardinal area, punctate shell structure, and distinct delthyrial plate which differs from that in *Syringothyris* in the entire absence of a syrinx upon its inner surface." Genotype, *P. missouriensis*. Other species are: *P. keokuk* and *P. gigas, Spiriferina latior.*

The genus *Acanthospira* differs from *Spiriferina* in the possession of a non-punctate shell and the absence of a median septum in the pedicle valve. It differs from *Spirifer* in the possession of fine spines. The genotype and only species known is *A. rowleyi*. The remaining new species described are: *Martinia sulcata, Ambocoelia unionensis, Reticularia salemensis, Eumetria acutirostrata, Nucleospira rowleyi, Cleiothyridina glenparkensis, C. lenticularis, C. scitula, C. laevis, C. pentagona, and C. globosa.*

There is no table showing the range of these species through the rocks of the Mississippian formations. This table would be of great assistance to stratigraphic geologists and paleontologists as well. Indeed the reviewer was tempted to prepare one and insert it in the review, since many of the species have a very limited range. However, it will probably accompany a study of the Mississippian formations at a later date when it will be more appropriate.

J. W. B.

"Features of Karakoram Glaciers Connected with Pressure, Especially of Affluents." By WILLIAM H. WORKMAN. *Zeitschrift für Gletscherkunde*. Bd. 8, 1913. Pp. 40, pl. 1.

Great relief, numerous large, high snow-fields, and a series of long, branching valleys reaching down from the uplands furnish the conditions in the Karakoram Mountains for a ramifying system of glaciers that exhibits phenomena lacking in most valley glaciers. The phenomena are chiefly connected with pressure, particularly that developed by affluent glaciers where they press down on their mains. The tremendous force of the tributary glacier, directed essentially at right angles to the direction of movement of the main glacier, forces the latter aside, but the affluent is shortly bent downward and moves parallel to the other glacier. The two glaciers crowd upon one another and are individually somewhat squeezed together, but they remain perfectly distinct, in some instances to a distance of 50 or 60 km. below the point of junction. Of particular interest is the union of the Siachen Glacier (4.4 km. wide, 40 km. long above this junction) and Tarim Shehr (3 km. wide, 25 km. long) which meet at an angle of about 140°. With much structural disturbance and a partial displacement of the main glacier, Tarim Shehr turns through 140° around a small promontory before it moves parallel to the main. Where the valleys are constricted the glaciers are notably narrowed, and the white ice tongues may completely disappear; but the glaciers do not spread to fill the wide parts of the valley.

Where the pressure of affluents on the main glacier is very great, the ice surface, especially along moraine-covered belts, is thrown up into rather irregular-shaped hillocks. Below the juncture of the two ice masses the hillocks become more pronounced, they are covered with piles of discrete débris, and become more or less united in a band parallel to the direction of ice movement; they are then termed "hillock moraines." Individual hillocks vary from 10 m. to 70 m. (exceptionally 150 m.) in height above the rest of the glacier. The moraine shows no evidence of having been pushed up from below or formed simply by differential melting. Transverse to the direction of pressure, white ice exhibits a series of long parallel ridges. Seracs have developed where there is a steepening of the gradient of the glacier beds, where the ice of Tarim Shehr impinges upon a plowlike promontory, and where constriction of the valley causes longitudinal crevassing. It is concluded that differential melting is an important agent in increasing the height of moraine-covered belts down the glacier. Vertical bands parallel to the direction of movement of the ice are to be noted in all the glaciers;

some vertical sections show extensive folding, faulting, and foliation of the ice strata.

It is concluded that pressure has had a very important rôle in determining variations in the course of the glaciers, surface forms on the glaciers, especially hillock moraines, stratification, and local deformation of the ice, and in the erosion accomplished.

R. C. M.

The Squantum Tillite. By ROBERT W. SAYLES. Bull. of the Museum of Comparative Zoölogy, Harvard College, Vol. LVI, No. 2, Geological series, Vol. X, 1914. Pp. 141–75, pls. 12.

The origin of the Roxbury conglomerate has always been a matter of doubt. It has been held by a number of geologists to be of glacial origin, while yet others have favored its marine derivation.

Robert W. Sayles in the present paper describes a bed of what appears to be tillite in the Roxbury series of Boston and vicinity. The Squantum tillite has a probable thickness of 600 feet and consists of sand, angular, subangular, and rounded pebbles and bowlders, and irregular fragments of slate. The size of the fragmental material varies from that of a sand grain to large, angular blocks, one bowlder having been found which has a length of 6 feet and a width of 1 foot. Practically all of the material is less than a foot in diameter, with the greater proportion less than 6 inches. All of these fragments are firmly cemented in a matrix of argillite. There are also intercalated beds of slate and conglomerate.

The criteria necessary for the recognition of tillite are enumerated and their application has been made to seventeen outcrops of this apparently glacial material. Mr. Sayles presents strong evidence in favor of the glacial origin of the Squantum tillite. The illustrated bowlders and pebbles have a subangular outline and also show fairly distinct striae. A striated bedrock has not been found, but this may be due to the nature of the underlying rocks, which are slates and sandstones.

In one locality the contact with the tillite and underlying sandstone was very ragged, the suggestion being made that the sand deposit, before having been firmly cemented, had been disrupted by violent movements of the ice.

The supposition is made that the movement of the glacier was from the southeast, and that as the advance took place into the Boston basin, the recently deposited beds of sand and clay were torn up and the fragments mingled with the débris of the glacier. The intercalated beds of slate, which become more numerous toward the top of the tillite, are

indicated as representing successive lengthening of the periods of the ice retreat, the slate present above the tillite representing the final retreat of the ice, followed by subsidence and deposition.

The age of the Squantum tillite is given as Permo-Carboniferous, with a probability that because of the widespread Permian glaciation it may be Permian.

C. B. A.

"Die Gletscher des Sarekgebirges und ihre Untersuchung." By AXEL HAMBERG. *Sveriges geologiska undersökning*, Ser. Ca., I, 4:o, No. 5. Pp. 26 (4mo), pls. 4.

The Sarekgebirge are the largest range in Sweden and contain more than 100 glaciers. Increase of snowfall toward the west, lower temperature in the north, and elevation above the sea determines the location of the larger and greater number of glaciers in the high, northwest part of the range. Winds are very strong, so topography has a very important influence in the locations of snow-fields. At high altitudes, however, the work of hoarfrost (*Rauhfrost*) to some extent counterbalances the effect of the wind. Two types of glaciers are distinguished: (1) valley glaciers, mostly in young cirquelike valleys at the edge of the upland, ranging in length from a few hundred meters to 5 or 6 km.; and (2) plateau glaciers which form on the broadly undulating flat tops of some of the mountains. The latter are not like the convex surface *Inlandeistypus* of Norway. Cliff glaciers are present, also, in very subordinant number.

Experiments were made to determine the yearly snow accumulation at various points on some of the larger ice-fields. This was done by means of marked standards and showed:

At 1,200 m. elevation	0 accumulation = snow line
1,340 m. elevation	1.29 m. accumulation per year
1,440 m. elevation	2.16 m. accumulation per year
1,500 m. elevation	2.43 m. accumulation per year

Observations on the rate of melting at the surface of the glaciers were undertaken by means of bored holes, the bottoms of which were specially marked. This showed a very rapid decrease of melting with increased distance from the lower edge of the ice.

Dist. from glacier end (m.)	150	350	1,000	2,000
Elev. above sea (m.)	970	1,000	1,100	1,200
Melting in 1 year (cm.)	330	244	90	4

Measurements on a number of the larger glaciers of the rate of movement were made. These showed the differential movement in various parts of the individual glaciers and indicated a much greater speed of movement in the summer. Not any variation of importance has been observed in the position of the lower end of the larger glaciers in recent years.

R. C. M.

"Die Geomorphologie und Quartärgeologie des Sarekgebirges." By AXEL HAMBERG. *Geol. fören. förhandl.*, Bd. 32, Heft. 4, April, 1910. Pp. 25, map 1.

The Sarekgebirge (north Sweden) are made up of the following rocks:

4. Amphibolite (1,000–1,200 m.)
3. Syenite (350 m.)
2. Silurian beds (150 m.)
1. Basement complex

The topography shows a striking dependence on the structural relations and resistance of the rocks. As an example is cited the development of numerous falls where the easily eroded Silurian shales have been weathered from beneath the resistant syenite. The mountain massifs are mostly flat-topped, possibly indicating remnants of an old erosion surface. Large deep valleys have been cut in the amphibolite but not far into the syenite. This is doubtless due to the superior resistance of the latter, not to any interruption of a former drainage cycle.

The Sarekgebirge were almost certainly a center of ice dispersion in the early Pleistocene. The presence of erratics from some distance to the southeast indicates that the center of ice movement later changed in this direction. In the retreat of the ice there was apparently a time when the ice from the southeast was no longer able to move up the slope of the mountains, and lakes were formed between the valley walls and the edge of the ice. Shore-line phenomena, especially where the valley walls are less steep, mark the levels of these lakes, but because the outlet over the ice was continually and gradually lowered, the level of the lakes was inconstant, and instead of a few sharply defined beaches there are a large number of indistinct shore lines. Ice blocks left at certain places in the valleys seem to have determined in part the courses of certain

glacial streams which are independent of the present topography of the valleys.

Glaciers are now the most important erosive agents in the Sarekgebirge. Because of the altitude, frost, ice, and daily temperature range have developed extensive rock-fields, or on steep slopes, large talus piles. Deltas have, in a number of places, been built in the lakes by the heavily mud-laden streams from the glaciers. As an indication of the immense amount of post-glacial filling may be cited the extinction of one or more considerable lakes by this process.

R. C. M.

A Geologic Reconnaissance of a Part of the Rampart Quadrangle, Alaska. By HENRY M. EAKIN. Bull. U.S. Geol. Surv. No. 535, 1913. Pp. 38.

This report takes into account the Rampart and Hot Springs district which include most of the triangular area between the Yukon and Tanana rivers west of longitude 150°, and a strip of territory on the north side of the Yukon that extends nearly to longitude 154°. The base of the geologic column is formed by a series of metamorphic rocks which consists of probable Silurian and Devonian limestones and schists, late Paleozoic greenstones (that contain some sedimentary beds), early Mesozoic slates, sandstones, and conglomerates, Cretaceous and older slates, quartzites, and schists. All of these beds are closely folded. The metamorphic series is overlain locally by Eocene beds which represent part of the notable fluviatile deposition of Eocene time, "evidence of which is widespread in Alaska." The strata are considerably folded and faulted. A good part of the region is mantled by Quaternary silt, sand, and gravel deposits. The silt is probably of glacial origin. The igneous rocks consist of probable late Paleozoic rhyolite flows, tuffs, and flow breccias, probably late Paleozoic basic flows, tuffs, diabase, glassy lavas, and tuffs, late Mesozoic or early Tertiary monzonite sills and batholiths with numerous dikes. Erosion occurred in post-early Mesozoic, post-Lower Cretaceous, post-Upper Cretaceous, and in post-Tertiary times. Placer gold is the only mineral of economic importance. The gold and silver production of the Rampart district is decreasing while that of the Hot Springs district is rapidly increasing. The largest output of the latter district was in 1911. The placer gold has been derived from quartz veins in the old metamorphic rocks, from carbonaceous beds, and from hematite deposits in the neighborhood of monzonite. The placers are of two types—those of present stream and those of terrace gravels. Pebbles of cassiterite occur with the gold in the Sullivan Creek placers but are not worked to any extent.

V. O. T.

"Untersuchung über Gletscherstruktur und Gletscherbewegung." By HANS PHILLIP. *Geologische Rundschau*, Bd. 5, Heft 3, März, 1914. Pp. 6.

The author has just completed observations on the arctic glaciers of Spitzbergen and the valley glaciers of the Alps and states he finds "banding a specific property of all ice-masses moving of themselves." Opportunity to observe the structure of these bands on the vertical faces at end and sides of a number of glaciers indicates a conformability of the bands to the shape of the valley containing the glacier; they are hence "trough-shaped." The bands are not formed by pressure analogous to that which forms slaty cleavage in rocks, for they are alternately of blue, compact ice and white, air-filled ice. Neither are they the original bedding of the snow-field for in certain instances this is seen in conjunction with the longitudinal banding. The bands are separated by deep cracks (*Rissen*) about 2 cm. wide and traceable for as much as 100 m. The cracks are from one-half to two meters apart and, like the bands, are trough-shaped. Careful measurement has shown a differential movement of the bands separated by the cracks. On the average this differential movement was 20 cm. in six weeks, with the greatest movement a short distance below the surface.

The writer concludes that the trough-shaped cracks between the bands indicate a differential movement of the bands. The movement along the cracks produces the white, air-filled bands by crushing the ice fragments. This conception of glacier movement is to be distinguished from the notion of movement by means of gliding planes (*Gleitfläche*) within the ice crystals.

R. C. M.

Corries, with Special Reference to Those of the Campsie Fells. By J. W. GREGORY. Trans. Geol. Soc. Glasgow, XV, Pt. I, 1912–13. Pp. 15, plates 2, figs. 4.

"Corries" (Scottish equivalent for "cirque," "Kar") are rounded amphitheater-shaped depressions with steep, smooth walls and flat floors. They have been explained (1) by glacial plucking at the head of small local glaciers during the last stage in the glaciation of a district, (2) by the action of a series of confluent waterfalls, each of which undercuts the rocks at its foot and leads to the erosion of a vertical cliff, and (3) by the alternate action of frost and thawing which disrupts the walls of the valley, while the floor is essentially protected from erosion by a

covering of snow and ice. The typical corries of Balglass, north of Glasgow, are described, and their origin attributed partly to the preglacial erosion of confluent water-falls, partly to the disruption of the wall rocks during glaciation by the agency of frost and ice.

R. C. M.

"Kurze Übersicht der Gletscher Schwedens." By AXEL HAMBERG. *Sveriges geologiska undersökning*, Ser. Ca., I, 4:0, No. 5. Pp. 8; 1 large topographic map showing glaciers.

The glaciers of Sweden are found in the high mountain area that extends along the international boundary between Sweden and Norway and in the northern part of Sweden, chiefly in the provinces of Jämtland and Lappland. The most southerly glacier is found in latitude 62° 55′ N. The glaciers of the north may be divided into an east and a west zone, the latter including the larger and greater number of glaciers. This distribution has climatic significance. There is a larger snowfall north and west because of the lower temperature and larger precipitation from the winds from the Atlantic. It is noted that the snow line is quite rapidly lowered to the north.

At lat. 63° N. elevation of snow line = 1,355 m.
At lat. 66° N. elevation of snow line = 1,245 m.
At lat. 68°5 N. elevation of snow line = 885 m.

Valley glaciers and plateau glaciers are distinguished; cliff glaciers are subordinate. A catalogue of the various glacier districts and the more important individual glaciers is given.

R. C. M.

"Nochmals zur Frage der Glazialbildungen in der Rhön. Erwiderung auf die Ausführung von A. Penck und Ed Brückner." By HANS PHILLIP. *Zeitschrift für Gletscherkunde*, Bd. 8, 1914. Pp. 4.

Philipp takes exception to statements made by Penck and Brückner relative to his report on cirques (*Kars*) of the Rhone Valley.

R. C. M.